Indonesian Society for Science Educators

Journal of Science Learning

journal homepage: ejournal.upi.edu/index.php/jslearning

Analogies Used in a General Biology Course: How is DNA Conserved Across Generations?

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ABSTRACT The present study has two main goals. First, it aims to examine the analogies an instructor uses about "DNA conservation across generations" in a university-level General Biology course. Second, it aims to examine the analogies used in those lessons according to Thiele and Treagust's framework. A qualitative case study design is adopted in the present study to investigate the cases in depth. Data were collected from an instructor with 35 years of teaching and research experience during a general biology course. According to the results, the instructor used many analogies, but seven of them were about to explain DNA conservation across generations. These analogies were analyzed by quoting the instructor and using figures and the classification mentioned above framework. It was noted that most of the analogies used by the instructor about DNA are structural-functional, verbal-pictorial, concrete, enriched, and embedded activators. For students to learn abstract concepts such as DNA correctly, this study provides examples of analogies that have been tried with well-established similarity relationships between source and target that engage students in the lesson. The effectiveness of the analogies on students' achievement and problem-solving skills can be tested in future studies.

Keywords Analogies, Biology education, General biology, Genetics instruction

1. INTRODUCTION

In science, that develops as systematic knowledge since no information alone makes sense; this discipline is based on linking scientific issues and daily life. When we consider science to learn, learning is possible by shedding light on learners' efforts to understand the world and increasing their interest in science, not memorizing information (Berber & Sarı, 2009). In addition, it occurs by getting to know the concept organizations unique to the learners and constructing new knowledge on them in subjects far above the learners' conceptual understanding skills (Çalık & Ayas, 2005). However, teaching primarily abstract, complex, and submicroscopic lessons, such as biology, is challenging by questioning and associating them (Lee & Kim, 2007; Chi, 2000), a global problem (Chu & Reid, 2012). The main reasons why the biology course is challenging to understand are that it is a rote-based course (Güneş & Güneş, 2005; Kaya & Gürbüz, 2002), students cannot associate the knowledge they have acquired in the learning environment with daily life (Doğan, Kırvak & Baran, 2004), and presenting theoretical concepts without concretizing (Jee et al., 2013). When little is known about a topic, the teacher should assist students in accessing the specific knowledge in a meaningful way (Mthethwa-Kunene, Onwu & de Villiers, 2015). For the last two decades, biology educators have made great efforts to examine the difficulties experienced by students regarding these abstract concepts (Bahar, Johnstone & Hansell, 1999; Duncan, Rogat & Yarden, 2009; Haskel-Ittah & Yarden, 2018; Johann, Rusk, Reiss & Groß, 2022; Kete, Horasan & Namdar, 2012; Lewis & Wood-Robinson, 2000; Todd & Kenyon, 2015). For concepts that cannot be experienced directly, concrete experiences can be used to understand the abstract concept (Lakoff & Johnson, 1980). This behavior we display naturally in our daily lives constitutes the basic philosophy of analogies—one of the teaching methods (Guerra-Ramos, 2011; Lancor, 2014; Mozzer & Justi, 2012).

Analogies enable the student to quickly assimilate and establish meaningful relationships with the help of their current prior knowledge of the concepts that they have just encountered and cannot think of abstractly (Brown, 1993; Else, Clement & Rea-Ramirez, 2008; Heywood, 2002;

Received: 25 May 2023
Revised: 01 October 2023
Published: 04 December 2023

Suryanda, Azrai, Nuramadhan & Ichsan, 2020; Thiele & Treagust, 1991). In other words, it is an analogy defining the similarities between two concepts (Glynn, 1991; Treagust, Harrison & Venville, 1998). Here, the concept known by the student is expressed as the source (analog), and the concept they have just encountered as the target concept (Gentner, 1983; Glynn, 1991). Analogies are simple, extended, enriched, verbal, pictorial, personal, bridging, and multiple analogies (Thiele & Treagust, 1991).

Each of the various types of analogies is unique, and it has been compared to a "double-edged sword" by Glynn (1989) because of its advantages and limitations. In the use of analogy, in addition to the benefits such as enabling the visualization of abstract concepts, connecting the words used in daily life with the new concept, and motivating the learner, there are limitations such as the learner not being familiar with the source, not presenting the analogy following the cognitive development stages of the learner, and the transfer of shared features incorrectly (Duit, 1991). Furthermore, teaching with analogies requires the teacher to be aware of students' concepts (Driver, 1989) and how they differ from scientific concepts (Johann, Rusk, Reiss & Groß, 2022; Vosniadou, 2014). Glynn & Takahashi (1998) mentioned the importance of science educators' understanding of the nature of analogies and structuring pedagogically effective analogies. In addition, based on the requirement that the subject area should be conceptually accessible to the student for effective teaching (Heywood & Parker, 1997), the use of analogy makes new ideas more plausible to students as well as motivating by creating cognitive conflict (Hutchison & Padgett, 2007; Lancor, 2014; Venville & Donovan, 2006), encouraging critical and creative thinking (Newton, 2003), and improving problem-solving, communication and creativity (Green, 2016; Green et al., 2017). Pedagogically sound analogies are found to affect student's interests and attitudes positively (Mthethwa-Kunene, Onwu, & de Villiers, 2015) and increase knowledge and motivation (Akaygun, Brown, Karatas, Supasorn & Yaseen, 2018; Azizoğlu, Aslan, & Pekcan, 2015; Glynn, 1991; Keller, 1983). Some research reported that analogies improve students' academic achievement (Azizoğlu, Aslan & Pekcan, 2015; Çoban, 2019; Zorluoğlu & Sözbilir, 2016). The research studies also reported that instructions using analogies are pedagogically effective in promoting conceptual understanding and eliminating existing misconceptions (Begolli & Richland, 2016; Bilgin & Geban, 2001; Gentner & Holyoak, 1997; Gilbert, 1989; Jensen, Kummer & Banjoko, 2013). For instance, Woody & Himelblau (2013) presented a collection of analogies to help students better understand the language of genetics. They argued that a solid foundation based on a thorough grasp of concepts used in genetics education is required for effective student instruction in biology. By using analogies, teachers can help their students understand the concepts of genetics more effectively.

Many research studies examined analogies either used in class or textbooks as one of the essential elements in science teaching and learning (Azizoğlu, Çamurcu, & Kırtak Ad, 2014; Blake, 2004; Braasch & Goldman, 2010; Orgill & Bodner, 2006; Paul, Lim, Salleh & Shahrill, 2019; Shana & El Shareef, 2022; Trujillo, Anderson & Pelaez, 2016). In different studies, different methods have been employed to teach with analogies. Specifically, in biology, various instructional methods have been used, such as computer-based analogies (Celik, Kirindi & Kotaman 2020; Rice & McArthur, 2002), genomics analogy model for educators (GAME) (Corn, Pittendrigh & Orvis, 2004; Rothhaar, Pittendrigh & Orvis, 2006), science texts with analogies (Marcelos & Nagem, 2012), directed inquiry approach supported with concrete analogies (Jensen, Kummer & Banjoko, 2013), self-generated analogies (Lancor, 2014), and analogy-based learning activities using the Model of Educational Reconstruction (Johann, Rusk, Reiss & Groß, 2022). All these studies show that a thorough understanding of the scientific concept to be learned depends on successful bridging between the target and the analog, that is, on the teacher's ability to teach with analogies. According to Shulman (1986, p.9), good teachers make the concept accessible to others by characteristically presenting the most valuable forms of content representation - the most substantial analogies, pictorial representations, examples, explanations, and demonstrations…that is, making the subject understandable to others. Here, the use and production of analogies in the classroom depend on the teacher's values, interests, pedagogical content knowledge, and the ability to encourage students to learn (Dagher, 1995).

Over the past 20 years, research in biology education has revealed that students have difficulty understanding biology concepts they cannot directly experience or see. The concept of DNA is one of them. Analogies play a crucial role in teaching DNA because they provide students with a bridge between the complex molecular world of genetics and their everyday experiences. DNA, the genetic code of life, is inherently abstract and microscopic, making it challenging for many students to grasp its intricacies without relatable comparisons. Teachers employ analogies to simplify these complex concepts, often likening DNA to a blueprint, a recipe, or code like a computer program. Such comparisons help students visualize the role of DNA in encoding genetic information, replication, and inheritance. Analogies provide a mental framework that aids comprehension and retention, making learning more engaging and accessible. The realm of DNA analogies offers intriguing insights to explain this previously asserted role. Metaphors and analogies profoundly influence our thought processes (Kumar, Manik & Joshi, 2023). Debruyn (2012) elucidates the chef analogy, as seen on Nova Science

Now, which likens the genome to a recipe book concealed in a lofty tower. This analogy employs the creation of tangible items like beaded bracelets or necklaces to convey the central dogma of molecular biology, representing a chain of amino acids. Niebert, Marsch & Treagust (2012) delve into the role of metaphors and analogies in grasping scientific concepts, introducing the "the gene is a code" analogy for when sources of understanding become ambiguous. This analogy hinges on the term "code," which refers to a system of words, numbers, or symbols for decoding secret messages (Niebert, Marsch & Treagust, 2012). In genetics, expressions such as 'code,' 'signal,' and 'messenger' are metaphorically employed as the most effective means of elucidating genetic phenomena (Blečić, 2021). Faltýnek, Matlach & Lacková (2019) highlight that the DNA and protein synthesis concept has been employed analogously to elucidate the natural language processing system. This analogy serves as a means to facilitate comprehension of the genetic code, its structure, and its functioning. Scaiewicz & Levitt (2015) present a repertoire of examples of this natural language, where the letters are DNA bases, words are codons, sentences are genes, syntax is folding rules, etc. Blečić (2021) also notes the prevalence of the "flow of information" discourse, elucidating the transmission from one generation to the next in molecular biology, underlining its significant teaching potential. DNA is depicted as an open book with unreadable chapters (Hesman Saey, 2018) and as a life blueprint, housing the instructions essential for an organism's growth, development, survival, and reproduction (Kumar, Manik & Joshi, 2023). McHughen (2020) intriguingly suggests that every nucleotide in the human body carries over 1000 Bibles worth of information, framing humans as time travelers in conveying genetic information. DNA is considered the universal language all species share. Kumar, Manik & Joshi (2023) introduce captivating phrases by Kenneth Ewart Boulding, describing DNA as the first three-dimensional Xerox machine, and by Sam Kean, equating genes to the story and DNA as the language in which the story is written. They also propose an alternative metaphor to the blueprint, likening DNA to computer programs. DNA comprises code segments instructing a larger system's hardware in this analogy. Some code segments are always active, while others run only under specific conditions, forming a dynamic computational network. Rothhaar, Pittendrigh & Orvis (2006) applied the Lego® Analogy Model, where the Lego® blocks were used to explain how genes are sequenced. The results of the classroom application have confirmed that this analogy increases students' understanding of gene sequencing (Rothhaar, Pittendrigh & Orvis, 2006). Johann, Rusk, Reiss & Groß (2022) designed and applied analogy-based learning activities regarding cell membrane biology and reported that students can develop and improve their understanding of the terms of cell membrane biology as a result of instruction with analogies. Trujillo, Anderson & Pelaez (2016) used the MACH model, one component incorporating analogies. They argued that this model may be insightful for exploring learning when students know little about a topic. Teaching with analogies can be used successfully both to eliminate and reveal misconceptions. In a study, Akgül & Çolak (2022) examined the story analogies developed by prospective science teachers. They observed pre-service teachers' misconceptions about developing story analogies for genes, DNA, and chromosomes.

By introducing a collection of analogies about "DNA conservation across generations," the present study also aimed to help teachers use the power of analogies in challenging issues of genetics instruction. Besides, these collections may increase students' familiarity with such analogies. To set an example, a biology question asked in the university entrance exam held in Turkey in 2020 presents the analogy of "This event is similar to watching an encrypted broadcast on television, that is, the broadcast from the center reaches every television, but this broadcast can be watched on televisions with a decoder" it was questioned which biological event this could be associated with. In this sense, it can be seen that it is essential for teachers to make students familiar with analogies by presenting such analogies in lessons. Within this context, the research questions of this study are as follows:

1) What analogies are used by an instructor in "DNA conservation across generations" in a university-level General Biology course?

2) according to the Thiele & Treagust (1994) analogy classification framework, what analogies are used in the lessons?

2. METHOD

2.1 Study Design and Context

In this study, a qualitative case study design, which is used to investigate one or two limited cases in depth, with multiple data collection tools to define situations/themes, was used as a research design. (Creswell, 2007). The data were collected in the courses of an instructor who teaches biology education to freshmen biology teacher candidates. Before the actual work, the instructor's lessons were observed for two hours to understand the teaching method. It was determined that although the lecturer seems to be teaching traditionally at first glance, he is entirely in charge and guides the lessons. It was noted that the instructor presents the concepts in connection with the student's daily life experiences, often asks questions, discusses answers with students, frequently uses analogies and stories, uses images, illustrations, and models to concretize the concepts, and actively uses the blackboard.

The instructor has 35 years of experience as a biology teacher in high schools and as a biology educator at the university. It is noticeable that this experience enables the

Table 1 Analogy classification framework categories used in the study (adapted from Thiele & Treagust, 1994)

Criteria	Analogy Type	Explanation
Shared Feature	a. Structural b. Functional c. Structural-functional	Of the two concepts shared in the analogy; a. Similar to external features/ appearances b. Their behavior or functions are similar c. Both their external features/ appearance and behavior or functions are similar
Presentation format	a. Verbal b. Verbal-visual	The analogy; a. Presented only verbally b. Presented both verbally and visually
Abstraction level/condition	a. Concrete-abstract b. Abstract-abstract c. Concrete-concrete	The first concept is analog; the second concept indicates the goal. Concrete concepts are concepts students can see, touch, smell, or feel in their daily lives.
The extent of mapping/ Level of achievement	a. Simple b. Enriched c. Extended	In the analogy a. The relationship between target and source concepts is not explained b. Describes not only the source to target match but also the reason for this mapping c. An analogy with over one analog or feature is used to explain a target
Source position about the target	a. Marginalized b. Pre-organizer c. Embedded activator d. Post-synthesizer	a. Employing the margin space in the textbook to present analogies b. The source is presented before the target c. The source is presented with the target concept d. After the goal is discussed, the source is presented

instructor to be aware of the readiness, prior knowledge, and misconceptions of university students coming from high schools in various regions of the country.

2.2 Data Collection

In case studies, interviews, focus group meetings, observation, or document analysis are used as data collection tools. Document analysis was used as a data collection tool in the present study. Document analysis is a systematic procedure to examine or evaluate documents such as text or images recorded without the intervention of a researcher (Bowen, 2009). The reason for using video capture and video analysis is to conduct a multimodal analysis that includes various meaning-making resources developed by the instructor, such as facial expressions, body language, and non-verbal analogies. In addition, the instructor's board work was also examined to detect and effectively capture the presence of analogies shown with figures on the board.

The instructor completed the "Genetics" unit in a university freshmen-level General Biology course within 18 lesson hours (18x45 minutes). The instruction of the whole Genetics unit was video recorded. During this unit, the "Molecular Basis of Inheritance" and the "From Genes to Protein" topics took 4 lesson hours (4x45 minutes), and the analogies presented in this study were related to these two topics. After determining which scenes would be utilized in the study, these scenes were pulled from video recordings and transcribed one-to-one. Screenshots of selected scenes were obtained to corroborate the findings.

2.3 Data Analysis

Data analysis in research requires organizing data systematically and collecting them in similar categories (Sagor, 2000). In this qualitative study, the transcripts obtained from the videos were used as critical data to find the most relevant aspects of the videos. These transcripts also included verbal and non-verbal events. To protect participant privacy and confidentiality, only instructors' picture frames were used to support the data analysis. The following steps were used to create a framework for data analysis: descriptive analysis, processing the data according to the thematic framework, defining the findings, and interpreting the findings following the qualitative data analysis (Yıldırım & Şimşek, 2005). In the first part of the study, the analogies used by the instructor during four-period lessons were determined. Then, the analogies related to how DNA is conserved across generations of subjects were extracted and presented to show how they were used. In the second part of the study, these extracted analogies used by the instructor were classified and analyzed according to the analogy classification framework of Thiele & Treagust (1994), shown in Table 1.

3. RESULT AND DISCUSSION

The present study aimed to examine analogies used by an instructor in a university-level General Biology course and categorize these analogies using the analogy classification framework. The results are presented in three parts: results of the quantitative analysis of the analogies used by the instructor in the lessons, results of the

Table 2 Number of analogies used by the instructor in the lessons

	Lesson1	Lesson2	Lesson3	Lesson4	Total
Number of analogies related to the DNA conservation across generations of subject	1	2	2	2	7
Number of analogies related to the other concepts of genetics topic	3	4	3	2	12
Total	4	6	5	4	19

qualitative analysis of the analogies about DNA conservation across generations of subjects, and results on the classification work of the analogies about DNA conservation across generations.

3.1 Results of the Quantitative Analysis of Analogies Used by the Instructor in the Lessons

When the transcripts obtained from the video recordings performed during four lessons were analyzed, it was seen that the instructor used 19 analogies related to the topic "Nucleic Acids and Protein Synthesis" during the lessons. Furthermore, it was found that seven of these analogies were related to the subject of "DNA conservation across generations." Table 2 presents the number of analogies the instructor uses in the lessons.

According to the findings obtained from the video recordings of the four lessons, it was seen that the instructor used analogy as if it were a natural part of his teaching process. Table 2 shows that during four lessons, the instructor used one to two analogies per lesson about DNA conservation across generations themes. As seen in Table 2, 12 analogies are not related to the conservation of DNA across generations but were used by the instructor for other basic concepts of nucleic acids and protein synthesis topics and were not included in this research.

3.2 Results of the Qualitative Analysis on Analogies of DNA Conservation Across Generations

The analogies used by the instructor on the subject were extracted from the transcripts of the video recordings. The seven analogies used by the instructor for DNA conservation across generations of subjects are described below.

H Bridges-Book Binding Analogy

The target: The DNA molecule comprises two complementary nucleotide chains. Each base in the chain has formed a pair with its specific partner (AT and GC) thanks to hydrogen bonds. These two chains are separated in the first stage of replication. When replication does not occur in the cell, hydrogen bonds exist between DNA nucleotides (Campbell & Reece, 2008).

The analogy used by the instructor to explain this target is:

Instructor: Based on our knowledge, DNA formed/accumulated in 3.5 billion years. The forehead and 1st Code of every living being are in DNA. For this reason, DNA must be protected. Especially when it won't work, when the genes on it won't be read. One of these protective factors is between the two chains [by drawing the H bridges on the DNA chemical structure he had previously drawn on the board]. Look, I'm not saying the H bond; the chemists get angry. Why? Because they say, H bonds are strong bonds, but you say weak H bonds are here. Then they could be called bridges, maybe adhesions, or hydrogen bridges. It can build two bridges between A and T and three between G and S. Two chains are connected by H bridges. When? When it won't work. What do we mean by his work? [Awaiting students to answer]

Student: [by answering] DNA's semi-conservative replication to transfer the information it carries to new cells/offspring.

Instructor: It can happen. What else? [awaiting answers from students]

Students: [Nobody answers] …

Instructor: For example, it will synthesize mRNA to direct the cell's metabolic events. What will it [meaning the DNA] do when it is not working? Can this formation/accumulation that makes us who we are, be left unprotected? Let us say we have a book, and let's conceive it as a precious book. We have bound the pages of our book so that they are not scattered. When we read, we open it, read it, then close the book's cover and secure it. Think like this. Then you will conceive it as if we have secured it with H brides ...

In this case, the hydrogen bonds between the DNA nucleotides are compared to the book cover, preventing the book from dispersing. The separation of these nucleotides during replication is likened to the opening of the cover when the book is read. Figure 1 shows a frame from the video recording.

Figure 1 H bridges-book binding analogy in class display

DNA and mRNA Relationship-The Boss and the Worker Relationship Analogy

The target: Although genes carry the information necessary to make specific proteins, a gene does not directly make a protein. RNAs are the bridge between DNA and protein synthesis. Transcription, the first stage in which a protein can be synthesized, can be defined as RNA synthesis under the direction of DNA (Campbell & Reece, 2008).

The analogy used by the instructor to explain this target is:

Instructor: You will think this when I say the meaningful chain. The gene was stimulated open, the H bridges between the two nucleotide chains were broken, and one of these chains molded into mRNA synthesis. So, the DNA codes will transmit to RNA in codon form, that meaningful chain. Then the gene was stimulated, the H bridges were disconnected, and someone passed the information to the mRNA, his boss; it would not come out or out of the nucleus. Where will this boss give the order? It will give it to the cytoplasm so that the metabolism there goes. Then he sends the command to the cytoplasm with the mRNA.

Here, DNA, which transfers the information of the protein to be synthesized to the cytoplasm via mRNA, is similar to a boss who uses her employee to perform any task.

The Protein Sheath of Nuclear DNA-The Human Outfit Analogy

The target: Nucleoproteins in eukaryotic cells are so named because of a protein sheath surrounding the DNA. The purpose of the protein coat in this structure is to protect the DNA molecule.

The instructor explained this target by using the following analogy.

Instructor: [Showing the DNA chain, he drew on the board and added OH to each phosphate as he drew it] This nucleotide has phosphoric acid. This acid has three hydroxyls. Two of them were used in polymerization. The third is attached to the amine group of the surrounding protein. Then think here in the same way. The main thing here is my own body. I have a dress on my body; I take off this dress and throw it away. Would I be without this? It would be a shame; I mean a little. Something must be on the DNA, just like my dress, to protect it. Just as the suit protects me from cold and external influences, this protein sheath also protects the DNA.

Figure 2 Protein sheath-the human outfit analogy in class

Ring Structure of Mitochondria, Chloroplast, and Bacterial DNA-Rosary Structure Analogy

The target: The main component of mitochondria, chloroplasts, and bacterial genomes is a double-helix circular DNA molecule. These molecules form twists and loops in a complex but orderly fashion (Campbell & Reece, 2008).

The analogy used to explain this target is as follows:

Instructor: Only the nuclear DNA is in the form of the nucleoprotein, but let's think about mitochondria, chloroplast, and bacterial DNA. Their DNA is naked, but there is another conservation factor. So how did someone build this (pointing to the rosary in his hand)? Look, someone arranged this rosary. Both ends were tied together. What would happen if it wasn't tied up?

Students: It would dissipate.

Instructor: Would it dissipate? Here they say the chain does not break up, another nucleotide does not come and enter here, is not added, and the nucleotide is not lost. I am happy with this situation. Just like here (pointing to the rosary), the two ends of the DNA in the structures we have mentioned are connected in this way.

Ring-shaped naked DNAs do not have a protein coat like eukaryotic DNA but can preserve their structure. The reason here is analogous to connecting the two ends of a rosary to protect its structure. If we compare the rosary beads to the nucleotides, thanks to this ring structure, these beads cannot be separated from each other, their order cannot be disrupted, and no other nucleotides can enter between them. Thus, the genetic information that has lasted over generations is preserved as much as possible. Figure 3 shows this analogy with a visual and a frame from the video recording.

Figure 3 Ring-shaped DNA-rosary analogy
https://www.sciencephoto.com/media/200795/view/circular-dna-molecule-artwork

The Nucleus of DNA in Eukaryotes-Putting Money in the Safe Analogy

The target: One of the most distinctive features of eukaryotes is that the cell's genetic material is contained in one or several nuclei surrounded by a membrane (Baldauf, 2003).

The analogy used by the instructor to explain this target is:

Instructor: We said DNA was in the nucleus; He was the boss in his main office. So the cell keeps its genetic material in a protected area like the nucleus, thus, preserving existing inheritance information. What does this look like? That is, we keep our money in safes so that no one stealsand we do not losemoney.

The genetic material is in the nucleus, surrounded by the membrane, to keep it in a more protected cell area. This is similar to storing valuable things like money in a safe deposit box.

Having an Unreadable Chromosome Structure and not Being Read-Can Not Wearing a Shirt in the Pack Analogy

The target: During cell division, DNA is concentrated as chromosomes. If this fragile and centimeters-long chromosomal DNA had not been packaged tightly, it would not resist the force generated by the pull of the daughter chromosomes by the spindle threads during cell division; it would be fragmented (Tunner, Mclennan, Bates & White, 2004).

Figure 4 Chromosome structure-shirt in the pack analogy

The analogy used by the instructor to explain this target is:

Instructor: Could packaging genetic material as chromosomes be a conservation factor during cell division?

Students: Yes.

Instructor: Because the DNA will not be read. What's wrong? Regularly transferring current inheritance information to later offspring/cells. What does that look like? Your mother buys a New Year's gift. What does she do? She covers it with a gift wrap to be both aesthetic and protected. For example, we all know DNA is not read in prophase and metaphase. All genes related to cell division are activated, and necessary materials are formed in interphase. Then cell division proceeds, prophase, metaphase… In prophase and metaphase?

DNA is not read because it is packaged. As you cannot wear a packaged shirt ...

We put some important objects in a box or wrap them to protect them from external influences. DNA cannot be read during the phase and metaphase stages of cell division as the current inheritance information is packaged to transfer it to the subsequent progeny in a specific order. The DNA in the chromosome state cannot be read, just as you cannot wear a packaged shirt. Figure 4 shows a visual related to this analogy.

The Helix Structure of DNA-Braided Hair Analogy

The target: DNA has a double nucleotide-stranded helix structure. The two nucleotide strands of DNA are coiled around each other, each following a spiral path, resulting in two right-handed strands (Tunner, Mclennan, Bates & White, 2004).

Instructor: Let us consider two chains of DNA. (Showing the rosary in his hand) these two chains may be straight (pointing to the flat form of the rosary), right? It can also be wrapped (showing the rosary wrapped).

Instructor: There are two chains; why are they twisted like that? Is it the flat version of this, more susceptible to external influences, or is it a spiral form?

Students: Flat.

Instructor: Then the coiling of DNA, like the minaret ladder, is also a conservation factor. This curl is due to the zigzag phosphodiester bonds in phosphates and sugars. What can we compare this to? Let's say we're going out in windy weather; (pointing to one of the students) you can see this girl's hair is messy, DNA is like girl's hair, (pointing to another student) this girl is braided, which one's hair is more easily messed up?

Students: Open one.

Instructor: Then this way of doing DNA helps to preserve its form and structure.

In this way, the helix structure of DNA protects itself from external influences. This is similar to having messy hair in the wind, while the braided hair is not affected. This analogy is shown in Figure 5.

3.3 Results on the Classification of the Analogies of DNA Conservation Across Generations

To answer the second research question of the present study, the analogies about DNA conservation across generations extracted from the video transcripts were classified according to the classification framework of Thiele & Treagust (1994), and the findings are summarized in Table 3.

As shown in Table 3, the analogies used by the instructor for DNA conservation across generations are mainly in the type of functional analogies (5 out of 7) where

Figure 5 DNA helix-braided hair analogy

the function or behavior of the analog is attributed to the target according to the analogical relationship between the analog and the target. According to the presentation style, 4 analogies are verbal, but the remaining three are presented verbally and visually. When the abstraction level of analog and target is examined, it is noteworthy that all seven analogies are of the concrete-abstract type, including a concrete analog and an abstract target. When the seven analogies related to DNA conservation across generations are examined according to the enrichment levels/mapping scope, it is seen that the instructor primarily (5 out of 7) uses enriched analogies that include explanations and limitations regarding the shared features. According to the position of the source relative to the target, which is the last examined criterion, the four analogies are found to be embedded activators in which the target and the source are presented simultaneously just before the results are obtained. The three analogies were in the post-synthesizer type, in which the analog's presentation follows the target's announcement.

Table 3 Classification of the analogies about DNA conservation across generations

No	Target	Source	Target-Source Relationship	Classification
1	H Bridges	Book	Establishing hydrogen bridges between the two chains when the genes on the DNA cannot be read is similar to closing the cover when the book is not read.	Functional Verbal Concrete-abstract Enriched Post synthesizer
2	DNA and mRNA relationship	Boss relationship with the employee	The way DNA transfers its information to mRNA to transmit information from the nucleus to the cytoplasm is similar to the boss managing his worker to perform any task.	Functional Verbal Concrete-abstract Enriched Embedded activator
3	Protein sheath of nuclear DNA	The human outfit	The protein sheath that protects the nuclear DNA is similar to the shirt that protects the human from environmental influences.	Functional Verbal-visual Concrete-abstract Enriched Embedded activator
4	The ring structure of mitochondria, chloroplasts, and bacterial DNA	Rosary structure	The logic in the circular structure of mitochondria, chloroplasts, and bacterial DNA is similar to connecting the two ends of the rosary to preserve its structure.	Structural-Functional Verbal-visual Concrete-abstract Extended Embedded activator

Table 3 Classification of the analogies about DNA conservation across generations (*Continued*)

No	Target	Source	Target-Source Relationship	Classification
5	DNA is in the nucleus in eukaryotes	Putting the money in the safe	DNA in the nucleus of eukaryotes is similar to placing valuable money in a safe.	Functional Verbal Concrete-abstract Enriched Post synthesizer
6	During cell division chromosome structure not being read	Can not wearing a shirt in a pack	The way DNA is in the form of chromosomes during cell division is similar to packaging a shirt/gift. If DNA is not read in this process, it is like can not wearing a packaged shirt.	Functional Verbal Concrete-abstract Extended Post synthesizer
7	The helix structure of DNA	Braided hair	The nucleotides in the two chains of DNA form a spiral structure so that they do not move away from each other, similarto braiding the hair so that it does not fall apart.	Structural-Functional Verbal-visual Concrete-abstract Enriched Embedded activator

4. DISCUSSION

In this study, we saw how an instructor incorporated analogies into his biology lessons without using any teaching with analogies method. The instructor dragged the students into the analog-target mapping process by guiding the class discussions and explaining many features of DNA. Flexibility is one of the strengths of the analogical approach. The analogical approach allows instructors to present material to their students without drastically altering their teaching style and provides a set of principles to facilitate this process (Gray & Holyoak, 2021). One of these principles is that the instructor should consider the student's prior knowledge. It was observed that all the analogies used by the instructor in this study were related to the subject content, appropriate to the student's level, and associated with their daily life experiences. Once the analogy is presented to the students, it is essential to help them construct the similarities and differences between the target and the source and to find where the analogy breaks down. This process, called mapping, is considered the basic sub-process of analogy (Parsons & Davies, 2022). The mapping process is critical and must be done in the teachings with analogies to prevent student misconceptions. In the present study, the instructor also tried to reveal the students' DNA knowledge and misconceptions by using detailed analogical mapping. The use of multiple analogies can be proof of this effort. Treagust, Duit, Joslin & Lindauer (1992) suggested that the successful use of analogies in science classrooms requires a well-established repertoire of analogies and specific content in specific contexts. The present study observed that the instructor had a vast repertoire of analogies accumulated over the years and could present analogies for any feature of DNA to the students. Perhaps the experience of creating and using analogies over the years and accumulating useful ones can explain the instructor's ability to teach without rigidly bound by any teaching model with analogies.

Although textbooks are still considered teachers' primary source (Pekdağ & Azizoğlu, 2013), their inability to explain analogies (Thiele & Treagust, 1991) increases the teacher's responsibility in the teaching process. Some studies report a strong relationship between what teachers know and how they teach (De Jong, Veal & Van Driel, 2002). In the present study, since the students are biology teacher candidates, it is essential to draw attention to the possibility that they may use similar analogies to enrich their lessons in their future teaching by referring to analogies used by the instructor.

In the second stage of this study, the analogies used by the instructor were analyzed according to the classification framework of Thiele & Treagust (1994). The results showed that the instructor frequently used functional and structural-functional analogies rather than structural analogies. To focus attention on critical similarities, the similarities between analog and target should be described explicitly. This can be achieved through verbal descriptions of the similarities, with the instructor explicitly pointing to the fact that two entities play the same role in analogous situations (Gray & Holyoak, 2021). According to Duit (1991), the main strength of analogies comes from the functional area where valuable results can be obtained.

When the analogies used by the instructor are examined according to the presentation style, it is striking that some analogies include various visual materials such as pictures and objects, some are told in body language, and some are in verbal style. Visual elements to present analogies enable students to activate the cognitive process necessary for constructing mental images (Glynn, Duit & Thiele, 1995). Bean, Searles, Singer & Cowen (1990) showed that pictorial analogies are more effective in reconstructing biological concepts. Djudin & Grapragasem (2019) confirmed that pictorial analogy models can enhance students' achievement of the related topic and boost retention. Guerra-Ramos (2011) also stated in his review that analogies observed in the classroom were often presented using verbal descriptions and various physical materials. Presenting the analogies in multiple ways can make the lesson more interesting, help students think critically and creatively, and learn meaningfully (Han & Kim, 2019; Paul, Lim, Salleh & Shahrill, 2019).

According to the level of abstraction, it was noted that all seven analogies used were concrete-abstract analogies with a concrete analog (source) and an abstract target. In other words, the biological concepts that students cannot see or touch are tried to be explained using concrete concepts that students frequently encounter daily. Venville & Treagust (1997) stated that teachers and writers of the materials (books, etc.) could sometimes produce challenging analogies for students. Here, correctly explaining the analogies falls mainly on the teacher, which is extremely important as it will enable students to construct their knowledge correctly. Using concrete analogies for theoretical concepts (e.g., genes, DNA, chromosomes, alleles, etc.) benefits those less familiar with the material most. Using concrete analogies allows students to build a foundational conceptual framework by linking the new to the learned material and something they are familiar with (Jensen, Kummer & Banjoko, 2013).

Regarding the extension of mapping, it was observed that the instructor used enriched and expanded analogies rather than simple ones. Using enriched/expanded analogies in the course and supporting analogies with pictures can help to increase their efficiency (Demirci-Güler & Yağbasan, 2008). Some authors (Spiro, Feltovich, Coulson & Anderson, 1989) caution against using simple analogies, especially at higher learning levels. Because as the subject learned becomes more complex, the value of simple analogies decreases.

Looking at the position of the source, which is the last classification criterion, it was determined that the instructor used the analogies in the lessons as both an embedded activator and a post-synthesizer. A preferred approach regarding the position of the source relative to the target has not been found in the studies reviewed. For example, in Glynn's (1991) teaching with analogies model (TWA), the target concept is presented before the source concept. However, where the analogy will be used in the lesson may vary depending on the subject and the purpose of the teacher. In their study, Yılmaz & Yalın (2019) examined the effect of differently positioned analogies in online learning environments on learners' academic achievement and retention. They compared a non-analogy learning environment to the other three positions (pre-organizer, embedded activator, and post-synthesizer). They indicated that in terms of academic achievement and retention of learners, student achievement and retention levels were higher in the three environments than in a non-analogy environment. Therefore, teachers must decide for what purpose to use analogies in the lesson and present the analogy accordingly.

Analogies have benefits and limitations and are integral to biology and biology education (Baker & Lawson, 2001; Trujillo et al., 2016; Venville & Treagust, 1997). Analogical thinking is a process that enables learners to process information actively, establish meaningful connections, use knowledge and skills to define relationships, produce new knowledge by structuring relationships, and develop long-term memory (Brunner, Schoenlank, Williams & Wiss, 1999; Marcelos & Nagem, 2012). Learners' familiarity with analogies can help to increase student achievement and critical thinking skills (Brunner, Schoenlank, Williams & Wiss, 1999; Shana & El Shareef, 2022).

Although the learning outcomes associated with incorporating analogies into learning environments are typically positive, the approach has potential pitfalls. Students in the same class do not come to class with the same prior knowledge or cognitive property, which undoubtedly affects the effectiveness of any proposed educational intervention (Gray & Holyoak, 2021). Considering biology's abstract and complex nature, the teachers are responsible for using analogies, which should be presented in a way that does not cause confusion and misunderstanding in the learners' minds.

5. CONCLUSION

Although the results of this study were derived from data gathered over a short period, they are thought to act as a guide for researchers who focus on how biology teachers use analogies in their natural teaching processes and for teachers who choose to use analogies in their teaching process. In particular, this study is important in terms of being a resource for both teachers and teacher candidates in terms of presenting many analogies that can be used on a subject, such as DNA, which is abstract and difficult to be learned in nature.

REFERENCES

Akaygun, S., Brown, C., Karatas, F. O., Supasorn, S., & Yaseen, Z. (2018). Teaching chemistry with analogies around the world: views of teachers from four countries. In *International Perspectives on Chemistry Education Research and Practice* (pp. 129-146). American Chemical Society. https://doi.org/10.1021/bk-2018-1293.ch009

Akgül, G. D. & Çolak, N. (2022). DNA, gen ve kromozom kavramları için geliştirilen hikaye tarzındaki analojilerin değerlendirilmesi. *Sinerji Uluslararası Alan Eğitimi Araştırmaları Dergisi*, *3*(1), 1-23. https://doi.org/10.54971/synergy.1109208

Azizoğlu, N., Aslan, S., & Pekcan, S. (2015). The periodic system and teaching with analogies model: the effects of teaching method, gender, and motivation on students' achievement. *Elementary Education Online*, *14*(2), 472-488. https://doi.org/10.17051/io.2015.39450

Azizoğlu, N., Çamurcu, M., & Kırtak Ad, V. N. (2014). Identifying and classifying analogies used in the secondary physics textbooks. *Journal of Turkish Science Education*, *11*(2), 39-62. https://doi.org/10.12973/tused.10108a

Bahar, M., Johnstone, A. H., & Hansell, M. H. (1999). Revisiting learning difficulties in biology. *Journal of Biological Education, 33*(2), 84–86. https://doi.org/10.1080/00219266.1999.9655648

Baker, W. P., & Lawson, A. E. (2001). Complex instructional analogies and theoretical concept acquisition in college genetics. *Science Education*, *85*(6), 665–683. https://doi.org/10.1002/sce.1031

Baldauf, S. L. (2003). The deep roots of eukaryotes. *Science,* 300, 1703-1706. https://doi.org/10.1126/science.1085544

Bean T. W., Searles, D., Singer, H., & Cowen S. (1990). Learning concepts from biology text through pictorial analogies and an analogical study guide. *Journal of Educational Research*, *83*(4), 233-237. https://doi.org/10.1080/00220671.1990.10885961

Begolli, K. N., & Richland, L. E. (2016). Teaching mathematics by comparison: Analog visibility as a double-edged sword. *Journal of Educational Psychology*, *108*(2), 194-213. https://doi.org/10.1037/edu0000056

Berber, N. C., & Sari, M. (2009). Effectiveness of Pedagogical Analogical Models on Realization of Conceptual Change for Teaching Work Power Energy Concepts. *Journal of Gazi Educational Faculty*, *29*(1), 257-277. https://dergipark.org.tr/tr/pub/gefad/issue/6745/90697

Bilgin, İ. & Geban, Ö. (2001). The use of analogy to remove 10th grade students' misconceptions related to chemical equilibrium concepts. *Hacettepe University Journal of Education*, 20, 26-32.

Blake, A. (2004). Helping young children to see what is relevant and why: supporting cognitive change in earth science using analogy. *International Journal of Science Education*, *26*(15), 1855-1873. https://doi.org/10.1080/0950069042000266173

Blečić, M. (2022). The notion of 'information' in genetics: a pragmatic model. *Journal of Biological Education*, https://doi.org/10.1080/00219266.2021.2020876

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, *9*(2), 27-40. https://doi.org/10.3316/QRJ0902027

Braasch, J. L. G., & Goldman, S. R. (2010). The role of prior knowledge in learning from analogies in science texts, *Discourse Processes*, *47*(6), 447-479. https://doi.org/10.1080/01638530903420960

Brown, D. E. (1993). Refocusing core intuitions: a concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching*, *30*(10), 1273-1290. https://doi.org/10.1002/tea.3660301009

Brunner, G., Schoenlank, J., Williams, M., &Wiss, T. (1999). *Ridgewood analogies: critical and creative thinking across the curriculum, book 5*. Cambridge, MA: Educators Publishing Service.

Çalık, M., & Ayas, A (2005). A cross- age study on the understanding of chemical solution and their components. *International Education Journal*, *6*(1), 30-41. https://files.eric.ed.gov/fulltext/EJ854953.pdf

Campbell, N. A., & Reece, J. B. (2008). *Biyoloji* (E. Gündüz, A. Demirsoy, & İ. Türkan, Trans.). Ankara, Türkiye: Palme Yayınları.

Celik, H., Kirindi, T., & Kotaman, Y. A. (2020). The effect of the computer-based analogy used in science teaching on learning outcomes. *Journal of Turkish Science Education*, *17*(1), 73-93.. https://doi.org/10.36681/tused.2020.14

Chi, M. T. H. (2000). Cognitive understanding levels. In A. E. Kazdin (Ed.), *Encyclopedia of psychology* (Vol. 2, pp. 141–151). Washington, DC: American Psychological Association; Oxford University Press.

Chu, Y.-C., & Reid, N. (2012). Genetics at school level: addressing the difficulties. *Research in Science & Technological Education*, *30*(3), 285–309. https://doi.org/10.1080/02635143.2012.732059

Çoban, M. H. (2019). *The effect of analogy-based 5e learning model on the academic success of students with different learning styles in the teaching of the electrical energy unit* (Master's thesis). Adıyaman University, Adıyaman, Turkey.

Corn, J., Pittendrigh, B. R., & Orvis, K. S. (2004). Genomics analogy model for educators (GAME): From jumping genes to alternative splicing. *Journal of Biological Education*, *39*(1), 24-26. https://doi.org/10.1080/00219266.2004.9655950

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five approaches* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Dagher, Z. R. (1995). Analysis of analogies used by science teachers. *Journal of Research in Science Teaching*, *32*(3), 259-270. https://doi.org/10.1002/tea.3660320306

De Jong, O., Veal, W. R., & Van Driel, J. H. (2002). Exploring chemistry teachers' knowledge base. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemical education: towards research-based practice* (pp. 369–390). Dordrecht, Netherlands: Kluwer Academic. https://doi.org/10.1007/0-306-47977-X_16

DeBruyn, J. M. (2012). Teaching the central dogma of molecular biology using jewelry. *Journal of Microbiology & Biology Education*, *13*(1), 62-64. https://doi.org/10.1128/jmbe.v13i1.356.

Demirci-Güler P., & Yağbasan, R. (2008). The description of problems relating to analogies used in science and technology textbooks. *İnönü University Journal of the Faculty of Education*, *9*(16), 105-122. https://dergipark.org.tr/tr/pub/inuefd/issue/8707/108707

Djudin, T., & Grapragasem, S. (2019). The use of pictorial analogy to increase students achievement and its retention of physics lessons of direct current. *Jurnal Penelitian Fisika Dan Aplikasinya [Journal of Physics Research and Its Application*], *9*(2), 140–151. https://doi.org/10.26740/jpfa.v9n2.p140-151

Doğan, S., Kırvak, E., & Baran, Ş. (2004). The levels of secondary school students making connection between daily life and the knowledge gained during biology lectures. *Erzincan University Journal of Education Faculty*, *6*(1), 57- 63. https://dergipark.org.tr/en/pub/erziefd/issue/5993/79746

Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education*, *11*(5), 481–490. https://doi.org/10.1080/0950069890110501

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education,* 75, 649–672. https://doi.org/10.1002/sce.3730750606

Duncan, R. G., Rogat, A. D., & Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th–10th grades. *Journal of Research in Science Teaching*, *46*(6), 655– 674. https://doi.org/10.1002/tea.20312

Else, M. J., Clement, J., & Rea-Ramirez, M. A. (2008). Using analogies in science teaching and curriculum design: Some guidelines. In *Model based learning and instruction in science* (pp. 215-231). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-6494-4_12

Faltýnek, D., Matlach, V., & Lacková, Ľ. (2019). Bases are not letters: On the analogy between the genetic code and natural language by sequence analysis. *Biosemiotics*, *12*, 289-304. https://doi.org/10.1007/s12304-019-09353-z

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, 7, 155- 170. https://doi.org/10.1016/S0364-0213(83)80009-3

Gentner, D., & Holyoak, K. J. (1997). Reasoning and learning analogy. *American Psychologist*, *52*(1), 32-34. https://doi.org/10.1037/0003-066X.52.1.32

Gilbert, S. W. (1989). An evaluation of the use of analogy, simile, and metaphor in science texts. *Journal of Research in Science Teaching*, *26*(4), 315-327. https://doi.org/10.1002/tea.3660260405

Glynn, S. M. (1989). The teaching with analogies (TWA) model: Explaining concepts in expository text: In K.D. Muth (Ed.), *Children's Comprehension of Narrative and Expository Text: Research into Practice*. Newark, DE: International Reading Association.

Glynn, S. M. (1991). Explaining Science Concepts: A teaching-with-analogies model. S. In Glynn, R.Yeany, & B. Britton (Ed.), *The psychology of learning science* (pp. 219-240). Hillsdale, NJ: Erlbaum.

Glynn, S. M. (2008). Making science concepts meaningful to students: Teaching with analogies. In S. Mikelskis-Seifert, U. Ringelband, & M. Brückmann (Eds.), *Four decades of research in science education: From curriculum development to quality improvement* (pp. 113-125). Münster: Waxmann.

Glynn, S. M., & Takahashi, T. (1998). Learning from analogy- enhanced science text. *Journal of Research in Science Teaching*, *35*(10), 1129-1149. https://doi.org/10.1002/(SICI)1098-2736(199812)35:10<1129::AID-TEA5>3.0.CO;2-2

Glynn, S. M., Duit, R., & Thiele, R. B. (1995). Teaching science with analogies: A strategy for constructing knowledge. In S. M. Glynn

& R. Duit (Eds.), *Learning science in the schools: Research reforming practice* (pp. 247-273). Mahwah, NJ: Erlbaum.

Gray, M. E., & Holyoak, K. J. (2021). Teaching by analogy: from theory to practice. *Mind, Brain, and Education*, 15, 250-263. https://doi.org/10.1111/mbe.12288

Green, A. E. (2016). Creativity, within reason: Semantic distance and dynamic state creativity in relational thinking and reasoning. *Current Directions in Psychological Science*, *25*(1), 28–35. https://doi.org/10.1177/0963721415618485

Green, A. E., Spiegel, K. A., Giangrande, E. J., Weinberger, A. B., Gallagher, N. M., & Turkeltaub, P. E. (2017). Thinking cap plus thinking zap: TDCS of frontopolar cortex improves creative analogical reasoning and facilitates conscious augmentation of state creativity in verb generation. *Cerebral Cortex*, *27*(4), 2628–2639. https://doi.org/10.1093/cercor/bhw080

Guerra- Ramos, M. T. (2011). Analogies as tools for meaning making in elementary science education: How do they work in classroom settings? *Eurasia Journal of Mathematics, Science & Technology Education*, *7*(1), 29- 39. https://doi.org/10.12973/ejmste/75175

Güneş, M. H., & Güneş, T. (2005). Difficulties and their reasons in learning biology concepts in primary school students. *Gazi University Journal of Kırsehir Education Faculty, 6*(2), 169-175. https://dergipark.org.tr/tr/pub/kefad/issue/59538/856372

Han, M., & Kim, Hb. (2019). Elementary students' modeling using analogy models to reveal the hidden mechanism of the human respiratory system. *International Journal of Science and Mathematics Education*, 17, 923–942. https://doi.org/10.1007/s10763-018-9895-x

Haskel-Ittah, M., & Yarden, A. (2018). Students' conception of genetic phenomena and its effect on their ability to understand the underlying mechanism. *CBE Life Sciences Education*, *17*(36), 1-9. https://doi.org/10.1187/cbe.18-01-0014

Hesman Saey, T. (2018). Your DNA is an open book — but can't yet be fully read: the stories your genes can tell are currently full of blank pages. *Science News for Students*. https://www.sciencenewsforstudents.org/article/your-dna-open-book-cant-yet-be-fully-read

Heywood, D. & Parker, J. (1997): Confronting the analogy: primary teachers exploring the usefulness of analogies in the teaching and learning of electricity. *International Journal of Science Education*, *19*(8), 869-885. https://doi.org/10.1080/0950069970190801

Heywood, D. (2002). The place of analogies in science education. *Cambridge Journal of Education*, *32*(2), 64-75. https://doi.org/10.1080/03057640220147577

Hutchison, C. B. & Padgett, B. L. (2007). How to create and use analogies effectively in the teaching of science concepts. *Science Activities: Classroom Projects and Curriculum Ideas*, *44*(2), 69-72. https://doi.org/10.3200/SATS.44.2.69-72

Jee, B. D., Uttal, D. H., Gentner, D., Manduca, C., Shipley, T. F., & Sageman, B. (2013). Finding faults: Analogical comparison supports spatial concept learning in geoscience. *Cognitive Processing*, *14*(2), 175–187. https://doi.org/10.1007/s10339-013-0551-7

Jensen, J. L., Kummer, T. A., & Banjoko, A. (2013). Assessing the effects of prior conceptions on learning gene expression. *Journal of College Science Teaching*, *42*(4), 82-91. http://www.jstor.org/stable/43631926

Johann, L. I., Rusk, F. K. H., Reiss, M. J., & Groß, J. (2022). Upper secondary students' thinking pathways in cell membrane biology – an evidence-based development and evaluation of learning activities using the Model of Educational Reconstruction. *Journal of Biological Education*. https://doi.org/10.1080/00219266.2022.2026805

Kaya, E., & Gürbüz, H. (2002). The views of the high schools and vocational high schools students on the problems of biology teaching. *Erzincan University Journal of Education Faculty*, *4*(2), 11-21. https://dergipark.org.tr/tr/pub/erziefd/issue/5990/79724

Keller, J. M. (1983). Motivational design of instruction. In C. M. Reigeluth (Ed.), *Instructional design theories and models: an overview of their current status* (pp. 383-434). Routledge. https://doi.org/10.4324/9780203824283

Kete, R., Horasan, Y., & Namdar, B. (2012). Investigation of the conceptual understanding difficulties in 9th grade biology books about cell unit. *Elementary Education Online*, *11*(1), 95-106. https://dergipark.org.tr/tr/pub/ilkonline/issue/8590/106761

Kumar, P., Manik, R. K., & Joshi, A. (2023). DNA is a blue print of life: a yoga-based review. *European Chemical Bulletin, 12*(Special Issue 1), 1088-1095.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: The University of Chicago Press.

Lancor, R. A. (2014). Using student-generated analogies to investigate conceptions of energy: a multidisciplinary study. *International Journal of Science Education*, *36*(1), 1-23. https://doi.org/10.1080/09500693.2012.714512

Lee, W., & Kim, H. (2007). Gifted middle students' conceptual change of an enzyme by using systemic analogies during the interpretation of experimental results. *Journal of the Korean Association for Research in Science Education*, *27*(3), 212–224. https://koreascience.kr/journal/GHGOBX/v27n3.page

Lewis, J., & Wood-Robinson, R. C. (2000). Genes, chromosomes, cell division, and inheritance: Do students see any relationship? *International Journal of Science Education*, *22*(2), 177-195. https://doi.org/10.1080/095006900289949

Marcelos, M. F., & Nagem, R. L. (2012). Use of the "Tree" analogy in evolution teaching by biology teachers. *Science & Education*, 21, 507–541. https://doi.org/10.1007/s11191-011-9370-3

McHughen A. (2020). *DNA demystified: unravelling the double helix*. Oxford University Press.

Mozzer, N. B., & Justi, R (2012). Students' pre- and post-teaching analogical reasoning when they draw their analogies. *International Journal of Science Education*, *34*(3), 429-458. https://doi.org/10.1080/09500693.2011.593202

Mthethwa-Kunene, E., Onwu, G. O., & de Villiers, R. (2015). Exploring biology teachers' pedagogical content knowledge in the teaching of genetics in Swaziland science classrooms. *International Journal of Science Education*, *37*(7), 1140-1165. https://doi.org/10.1080/09500693.2015.1022624

Newton, L. D. (2003). The occurrence of analogies in elementary school science books. *Instructional Science*, 31, 353-375. https://doi.org/10.1023/A:1025706410666

Niebert, K., Marsch, S., & Treagust, D. F. (2012). Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science. *Science Education, 96*(5), 849-877. https://doi.org/10.1002/sce.21026

Orgill, M., & Bodner, G. M. (2006). An analysis of the effectiveness of analogy use in college-level biochemistry textbooks. *Journal of Research in Science Teaching*, *43*(10), 1040 1060. https://doi.org/10.1002/tea.20129

Parsons, J. D., & Davies, J. (2022). The neural correlates of analogy component processes. *Cognitive Science*, *46*(3), p. e13116. https://doi.org/10.1111/cogs.13116

Paul, A., Lim, A., Salleh, S. M., & Shahrill, M. (2019). Enhanced learning through analogy in the teaching of cardiovascular system. *Journal of Turkish Science Education*, *16*(2), 176-186. https://doi.org/10.12973/tused.10273a

Pekdağ, B., & Azizoğlu, N. (2013). Semantic mistakes and didactic difficulties in teaching the "amount of substance" concept: A useful model. *Chemistry Education Research and Practice*, *14*(1), 117-129. https://doi.org/10.1039/C2RP20132A

Rice, S., & McArthur, J. (2002). Computer analogies: teaching molecular biology and ecology.*Journal of College Science Teaching*, *32*(3), 176-181. http://www.jstor.org/stable/42991498

Rothhaar, R., Pittendrigh, B. R., & Orvis, K. (2006). The genomics analogy model for educators (GAME): The effectiveness of the Lego® model for teaching gene sequencing and biotechnology in high school classrooms. *Journal of Biological Education*, *40*(4), 166-171. https://doi.org/10.1080/00219266.2006.9656039

Sagor, R. (2000). *Guiding school improvement with action research*. Alexandria, VA: Association for Supervision and Curriculum Development.
Scaiewicz, A.& Levitt, M. (2015). The language of the protein universe. *Current Opinion in Genetics and Development,* 35, 50–56. https://doi.org/10.1016/j.gde.2015.08.010.
Shana, Z. A., & El Shareef, M. A. (2022). Science teachers' use of analogies: Findings from classroom practices. *European Journal of Educational Research*, *11*(2), 1023-1036. https://doi.org/10.12973/eu-jer.11.2.1023
Shulman, L.S. (1986) Those who understand: knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14. https://doi.org/10.3102/0013189X015002004
Spiro, R., Feltovich, P., Coulson, R. L., & Anderson, D. K. (1989). Multiple analogies for complex concepts: antidotes for analogy-induced misconception in advanced knowledge acquisition. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 498-528). Cambridge University Press. https://doi.org/10.1017/CBO9780511529863.023
Suryanda, A., Azrai, E. P., Nuramadhan, M., & Ichsan, I. Z. (2020). Analogy and critical thinking skills: Implementation learning strategy in biodiversity and environment topic. *Universal Journal of Educational Research*, *8*(4A), 45–50. https://doi.org/10.13189/ujer.2020.081807
Thiele, R. B., & Treagust, D. F. (1991). *Using analogies to aid understanding in secondary chemistry education* (ED349164). https://files.eric.ed.gov/fulltext/ED349164.pdf
Thiele, R. B., & Treagust, D. F. (1994). The nature and extent of analogies in secondary chemistry textbooks. *Instructional Science*, 22, 61–74. https://doi.org/10.1007/BF00889523
Todd, A., & Kenyon, L. (2015). Empirical refinements of a molecular genetics learning progression: The molecular constructs. *Journal of Research in Science Teaching, 53*(9), 1385–1418. https://doi.org/10.1002/tea.21262
Treagust, D. F., Duit, R., Joslin, P., & Lindauer, I. (1992). Science teachers' use of analogies: Observations from classroom practice. *International Journal of Science Education*, *14*(4), 413-422. https://doi.org/10.1080/0950069920140404
Treagust, D. F., Harrison A. G & Venville, G. J. (1998). Teaching science effectively with analogies: an approach for preservice and inservice teacher education. *Journal of Science Teacher Education*, *9*(2), 85-101. https://doi.org/10.1023/A:1009423030880
Trujillo, C. M., Anderson, T. R., & Pelaez, N. J. (2016). Exploring the MACH model's potential as a metacognitive tool to help undergraduate students monitor their explanations of biological mechanisms. *CBE-Life Sciences Education*, *15*(2), 1-16. https://doi.org/10.1187/cbe.15-03-0051
Tunner, P. C., Mclennan, A. G., Bates, A. D., White, M. R. H., & Konuk, M. (2004). Ökaryotik kromozom yapısı [Eucaryotic chromosome structure]. In M. Konuk (Ed.), S. Cenkci, M. Yıldız, A. Aktümsek, *Moleküler biyoloji önemli notlar [Molecular Biology]*. Ankara, Turkey: Nobel Yayın Dağıtım.
Venville, G. J., & Donovan, J. (2006). Analogies for life: a subjective view of analogies and metaphors used to teach genes and DNA. *Teaching Science*, *52*(1), 18-22. https://doi.org/10.3316/aeipt.152547
Venville, G. J., & Treagust, D. F. (1997). Analogies in biology Education: a contentious issue. *The American Biology Teacher*, *59*(5), 282-287. doi.org/10.2307/4450309
Vosniadou, S. (2014). Examining cognitive development from a conceptual change point of view: the framework theory approach. *European Journal of Developmental Psychology*, *11*(6), 1–17. https://doi.org/10.1080/17405629.2014.921153
Woody, S. & Himelblau, E. (2013). Understanding & teaching genetics using analogies. *The American Biology Teacher*, *75*(9), 664-669. doi.org/10.1525/abt.2013.75.9.7
Yıldırım, A., & Şimşek, H. (2005). *Sosyal bilimlerde nitel araştırma yöntemleri* (5.bs) *[Qualitative research methods in the social sciences, 5th ed.]*. Ankara, Turkey: Seçkin Yayıncılık.
Yılmaz, Y., & Yalın, H. (2019). The effect of analogies positioning differently on academic success and persistency in online learning process. *The Journal of Turkish Educational Sciences*, *17*(2), 443-462. https://dergipark.org.tr/en/pub/tebd/issue/50950/647450
Zorluoğlu, S. L., & Sözbilir, M. (2016). The effect of analogy technique applied to ionic and covalent bonds on student success. *Journal of Bayburt Education Faculty*, *11*(1), 84-99. https://dergipark.org.tr/en/pub/befdergi/issue/23129/247048