International Journal of Didactical Studies
Volume 1, Issue 1, 2020
www.ijods.com

Research Article

Physical model in understanding deoxyribonucleic acid: Moving from physical entity to molecular unit

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The conceptualisation of Deoxyribonucleid acid (DNA) molecule is imperative in understanding the dynamics of genetics. However, research has shown that many high school students leave the school often with little or no understanding of DNA molecule. For this, researchers who take on the constructivist approach suggest to couch the lessons on DNA through the use of physical model. Therefore, physical model-based learning unit was contrived to enhance students' conceptual understanding of structural and functional aspects of DNA molecule. The learning unit was implemented to thirty-eight (N=38) 10th-grade Bhutanese students. The data was collected through DNA conceptual test. The data gathered through the test was analysed based on the iterative process of coding scheme cycle developed by Chi (1997) and Miles and Huberman (1994). The result shows that the learning unit does, to a large extent, engender deeper understanding of DNA molecule. Specifically, the students' conceptual understanding was observed in the domain of structural and the functional aspects of DNA molecule.

Keywords: DNA molecule, analogical model, physical model, coding scheme

1. Introduction

Molecular genetics is the pinnacle of modern biology (Duncan, Freidenreich, Chinn, & Bausch, 2011). The saga of molecular genetics has dawned after the ideation of double helix molecular model of Deoxyribonucleic acid (DNA) by Watson and Crick in 1953 (Schindler, 2008. Since then, the concept of DNA has changed considerably from being an obtuse molecule to an icon of the modern genetics (Kılıç, Taber, & Winter bottom, 2016; Rotbain, Marbach-Ad, & Stavy, 2006; Tsui & Treagust, 2007). Today, the knowledge of DNA molecule has spawned myriads of splendors that everyone needs to understand (Dahm, 2005).

In the international arena, the details of DNA, in molecular point of view, are featured in middle secondary school curriculum (Dahm, 2005; Mills Shaw, Van Horne, Zhang, & Boughman, 2008). In Bhutanese curricular forefront, the molecular details of DNA, is offered 10th-grade onwards, although students in Grade 10 learn the basics of double helical structure of DNA molecule, nucleotides (sugar, phosphate, nitrogenous base), and hydrogen bonds (Ministry of Educaiton, [MoE], 2012; Tshering, 2016; Tshering, Dorji, & Timshina, 2014). However, a growing body of research argues that the concept of DNA molecule is seemingly incomprehensible, counterintuitive, and inherently difficult for students to have intelligible realm of understanding (Lewis, John, & Wood-Robinson, 2000a, 2000b; Mills Shaw, et al., 2008; Rotbain et al., 2006; Wood-Robinson, Lewis, & Leach, 2000; Saka, Cerrah, Akdeniz, & Ayas, 2006).

Generally, literature articulates three perspectives that atttribute difficulties in learning molecular details of a DNA molecule. First, DNA by nature, is an abstract entity, which is by far removed from the direct hands-on experience or the palpability of the sense organs (Knippels,

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Waarlo, & Boersma, 2005; Tibell & Rundgren, 2010). Kindfield noted that what makes learning about subcellular processes difficult is that we have virtually no direct experience with them (1992). Second, the structural aspects of DNA is complex or intricate that it is difficult to map every detail coherently (Lewis et al., 2000a; Tsui & Treagust, 2007; Wood-Robinson et al., 2000). Third, in most part of the classroom setting, DNA and its associated concepts are, taught often using graphical illustrations that leave many parts of the DNA molecule inaccessible (Knippels et al., 2005; Tibell & Rundgren, 2010). Given these difficulties in the instruction of molecular genetics including DNA, researchers who take a constructivist approach suggest to improve the teaching of molecular genetics through the use of models (Malacinski & Zell, 1996; Peebles & Leonard, 1987; Templin & Fetters, 2002a, 2002b). As per Rotbain et al. (2006) "it is worthwhile to integrate model activities (physical and graphical) in the teaching of molecular genetics in high schools" (p. 521). Therefore, the theoretical grounding of this study, described in the next section, is informed by the pedagogical perspective that emphasise the role of physical model in learning.

1.1. Theoretical Background

Models play an especially central role in understanding the molecular structure in general and the genetic material in particular (Rotbain et al., 2006).Theoretically, models are referred as the representation of knowledge, entities, events, concepts, processes, or systems (Coll, France, & 2005; Gilbert & Boulter, 1998; Hardwicke, 1995a, 1995b). In educational research, there are burgeoning repertoires that expound the prospects of model in teaching and learning (Gilbert & Boulter, 1998; Greca & Moreira 2000; Justi & Gilbert, 2002; Harrison & Treagust 1996; Van Driel & Verloop, 2002). Coll et al. (2005) opine that "models are key tools for science teachers and science learners when there is an attempt to make accessible to scientists' understandings and to provide some insight into their business" (p. 183). In canonical views, the model serve as a link between scientific theories and the realities (Gilbert, 2004), a bridge between students and scientific realities (Gilbert, Justi, & Aksela, 2003), or liaison the realities that are hidden and beyond the reach of the sensory modalities (Clark & Mathis, 2000).

Ideally, the function of model as bridge arises from its analogical relations with the reality. The fact that the models serve as a bridge between realities and theories, is derived from the word "analogy" and "it is the analogical relations that makes a model a model" (Duit & Glynn, 1996, p.167). However, there is a general consensus that the essence of analogy is maintained only when the entities bear the expression of a relation of equivalence or likeness (Coll et al., 2005) or when two domains share certain attributes and (parts of) structures (Duit & Glynn 1996; Venville & Donovan, 2008).

Classroom teaching use analogies to elucidate difficult concepts simple and render abstract ideas concrete by comparing less familiar ideas, systems, or concepts to more acclimatized ones (Dagher, 1995). Glynn and Takahashi (1998) ascertained the contributions of analogy to learning. They examined the impact of using the concept of a factory (familiar situation—source) as an analog to that of an animal cell (unfamiliar situation—target) on middle school students' learning. They engendered that students in the experimental group, who learned the factory as an analogy, had better immediate and 2-week recall, and better understanding of the target concept, than students in the control group, who learned without the analogy.

The model that bears the similarity of reality and theory is known as analogical model (Harrison & Treagust, 2000). Analogical model is used often in teaching to explain abstract science concept (Coll et al., 2005). Gentner and Holyoak (1997) mention that an analogy as a heuristic design helps to understand a novel situation in the context of one that is already known. The known scenario is —the source—an instrument for making extrapolation about the unfamiliar situation—the target analog. The analogical model that shares similarities between two domains makes possible to use high level cognitive mechanism, the analogical understanding, stated as a "transfer of knowledge from one situation to another by a process of mapping—finding a set of one-to-one correspondences" (Fischbein, 1987, p. 127). Therefore, researchers postulates that the analogy acts as linkage between students' existing knowledge and the new knowledge, enabling the target more perceptible and understandable.

In science education, the model that acts as an analogy of the target is called "pedagogical analogical model': "analogical" because it share feature with the target, and "pedagogical" because it is a teacher-contrived arguments that ensures non-observable entities, like atomic or molecular particles, perceptible to students (Harrison & Treagust as cited in Rotbain et al., 2006, p. 502). According to Gilbert and Boulter's (1998) classification, the model that exist in three-dimensional horizon are defined as an analogical physical (concrete) model. Therefore, in light of the theoretical framework, a physical model-based learning unit was developed to enhance 10th-grade students' conceptual understanding of DNA molecule. The learning unit was implemented to answer the questions:

1. Does the learning unit enhance students' conceptual understanding of DNA?
2. To what extent does the learning unit enhance students' conceptual understanding of

2. Method

2.1. Research Design

This study used one-group pretest-posttest design to ascertain the effect of the physical model-based learning unit. This research design was selected based on the two conditions of the study. First, this study required a single group of participants as part of a single condition—to give the same treatments and assessments. Second, it entailed the assessment of students' conceptual understanding before and after a treatment by calculating the differences (Allen, 2017).

2.2. Participants

This study was carried in the vicinity of Paro town situated in western Bhutan. The physical model-based learning unit was implemented in one of the higher secondary schools. The school was chosen as the study site purposefully based on two reasons; easy access to the researchers and was only school in the study area where 10th-grade students have not been taught about DNA molecule.

According to Teddlie and Yu (2007), the samples are, at times, deliberately recruited based on certain criteria, characteristics, or need of the study. In the similar manner, this study recruited 38 Grade 10 students as the research participants based on two inclusion criteria. First, students who have not been taught about DNA molecule were identified after consulting the teacher who was involved in teaching biology. Next, students were informed to join the study based on their interest and willingness.

2.3. Process

The research consisted of using Google Scholar and The University of Auckland search engines to find journal articles that had conducted studies into effectiveness of entrepreneurship education in primary, secondary and tertiary levels (Figure 2). These studies aimed to provide empirical evidence on the outcomes of entrepreneurship education from the viewpoint of students, teachers, lecturers, principals, or working adults. The review sought to understand the effectiveness of programmes in developing students' attitudes, skills, and competencies towards entrepreneurship.

The overall flow of the instruction was adapted, partly from, the idea of Peebles and Leonard's (1987) "Hands-on Approach … DNA Structure and Function" and Robertson's (2016) Summer 2016: Modelling DNA. Robertson's (2016) method of instruction contained the provision to observe DNA at the physical level, however, the style of the instruction did not contain the favour to experience the DNA at the molecular or atomic level. Conversely, Peebles and Leonard's (1987) approach to teaching DNA just contained the provision to manipulate the interacting entities of DNA molecule using models. As such, the physical model-based learning unit was contrived to form the instruction of DNA molecule from the physical aspects to the chemical entities by coalescing the ideas of Peebles and Leonard's (1987) and Robertson's (2016) instruction.

The learning unit was implemented was for a period of 90 min approximately on two consecutive days after the school hours. It was implemented by telling how DNA is commonly used in forensic science to solve the mystery of crime and paternity issue. Then an essential question was asked: How is DNA seen at the physical level? To visualise the DNA at the physical level, students extracted DNA from onion peel based on the DNA extraction protocol (see Appendix A) designed by Friedman (2017).

After the DNA extraction, the participants were challenged with: i) How is DNA molecule seen at the chemical level or molecular level? ii) What constitute the DNA molecule? , iii) What is DNA's role? , and iv) How is DNA's role related with the cellular activities and the corresponding body features of the organisms? The traditional setting of classroom instruction focuses solely on the structure of DNA and the details of information stored by the genetic code, with little discussion of how the proteins mediate the genetic effects (Duncan & Tseng, 2010). Thefore, the fourth question looks beyond the scope of the DNA molecule per se, but it certainly has the value in terms of relating how the information stored in DNA brings about the effects on the corresponding biological levels.

To answer the four preceding essential questions, the excerpt on DNA molecule (see Appendix B) was distributed to the participants. The excerpt provided lens into the chemical composition of the DNA molecule, biological role of DNA, and the corresponding genetic phenomena prevailing across different levels of biological organisation. The excerpt contained text about the DNA molecule, instructions and guiding questions related to the chemical structure of nucleotides and chemical structure of a DNA molecule adapted from Duncan and Reiser (2007) and Rotbain's et al., (2006). After the reading the excerpt, participants performed body modeling activity as shown in Figure 2. During the activity, each participant represented a nucleotide with shoulder as the pentose sugar, fist of the left hand as phosphate group, and fist of the right hand as the nitrogenous base. Students lined up forming two lines facing opposite to each other. Students chanted the rhythm in unison "I am a nucleotide … my shoulder is my pentose sugar … my left hand fist is my phosphate group…my right hand is my nitrogenous base".

Follow up to the body modeling activity, participants modeled linear model of DNA molecule as shown in Figure 3. They made the model of nucleotides using locally available materials and joined the nucleotides to make the DNA strands. Two strips of chart paper cut into 15 cm by 2 cm represented two strands of DNA. The cardboard cut into pentagonal structures and marked in red represented pentose sugar. The white circular structures prepared from A4 size paper was placed in between the pentose sugars to represent the phosphate groups. The rung placed between the two stripes of chart paper represented nitrogenous base-pairs. The complementary nitrogenous base-pairs (adenine with thymine-AT and guanine with cytosine-GC) on each rung was written using board marker. Each part of the nucleotide was attached against the two stripes of strands using Fevicol.

Next, participants also built 3D helical model of DNA as shown in Figure 3. They made ball-like structures out of Styrofoam board using sand paper to represent nucleotides. A hole was made through each ball using a pointed stick. Each ball was lined up through the thread put through their hole. Two lines of balls were intertwined to represent helical model of DNA.

Figure 1. Extraction of DNA from onion peel

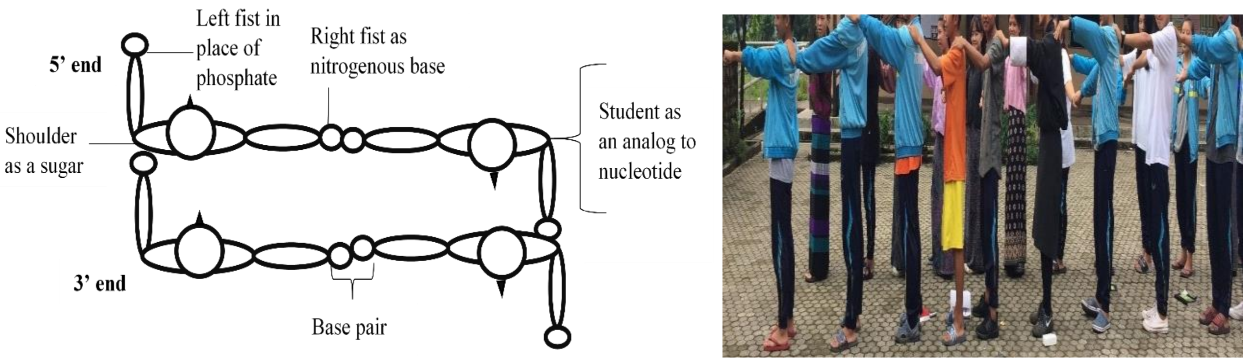

Figure 2. Enactment during the body modelling activity

Figure 3. Construction of linear and 3D helical model of DNA

2.3. Data Collection and Data Analysis

DNA conceptual test (pretest and posttest) ascertained students' conceptual understanding of structural and functional aspects of DNA molecule. The test contained four subjective questions that entailed students to give written response. It was implemented before and after the intervention. The test items were adapted from the test designed by Rotbain et al. (2006).

The test items were validated by two lecturers from Samtse College of Education, Royal University of Bhutan. The test was piloted with 22 Grade 10 students from one higher secondary school who have learnt about DNA molecule. The item difficulty index (P value) and item discrimination index (D value) of the test was in the acceptable range from 0.38 to 0.75 and 0.38 to 0.78 respectively. However, the internal consistency of the test items were poor. As such, the items that did not show inter-item correlation were eliminated to make the internal consistency 0.78. Thus, the number of test items got reduced to four subjective questions.

Students' conceptual understanding of DNA molecule was analysed through an iterative process of construction and refinement of the coding schemes advocated by Chi (1997) and Miles and Huberman (1994). During the analysis of the data, students' responses against question were coded against each level of codes of the coding schemes. The number of responses against each category of code in both pretest and posttest were then tabulated in terms of percentage (%).

3. Results and Discussion

3.1. Students' Conceptual Understanding of DNA molecule

The study ascertained students' response to pre-posttest DNA conceptual test. Students' responses to first question "What is DNA?" are revealed in Table 1.

Table 1
The Conception of DNA Molecule

Category of Codes	**Response per Category (%)**	
	Pretest	**Posttest**
DNA is a molecule which consists of two nucleotide strands twisted together (structure). The nucleotide sequence encodes instructions for synthesising proteins	0	87
DNA is a molecule which consists of two nucleotide strands twisted together (structure)	0	3
DNA is a molecule which encodes instructions for synthesising proteins	0	4
DNA is a molecule which consists of nucleotide sequence	2	0
DNA is a deoxyribonucleic acid which control cell activities	85	0
DNA is a deoxyribonucleic acid	13	0
Incorrect answer/No answer	0	0

In pretest, students fell short of giving coherent and matured view of DNA molecule. There was no response that explained DNA from both the structural and functional aspects. Though a few participants (2 %) managed to explain DNA either from the functional or structural aspects, their understanding was by far shallow and premature. Not surprisingly, 85 % of the participants described DNA as an organelle that regulates the cellular activities. As such, this conception without a doubt was deterministic in nature. This type of connotation indicates that According to Duncan and Reiser (2007), the view of DNA as the genetic material which specifies any and all of the bio-physical functional levels (deterministic in nature or passive particle), is far from the construe of the scientific community. DNA as the deterministic entity or the passive particle (Venville and Treagust, 1998) appeared identical to the concepts defined in seventh and eighth-grade science textbooks; and ninth-biology textbook (Royal Education Council [REC], 2017a, 2017b; Tshering, Dorji, & Timshina, 2014).

Oppositely, participants' responses in posttest alluded their conceptual change trajectory. Majority (87 %) of the participants described DNA as a molecule composed of two strands of nucleotide sequence containing information to synthesise protein. Their explanation of DNA encompassing the idea of both the structural and functional aspects, is by and large, in line to the view of the scientific understanding. According to Rotbain et al. (2006), the correct answer to the explanation of DNA should refer to two aspects: the function of DNA (DNA as genetic material) and its molecular structure. Rotbain et al. (2006) have also obtained similar results in their study conducted to enhance 11th and 12th-grade students' understanding of molecular genetics through bead and illustration model. According to Schindler (2008), and Travers and Muskhelishvili (2015), DNA molecule is a genetic material composed two strands of nucleotide chains that is encoded with information to build the organism or protein or RNA. Similarly, Tshering (2016), Tshering et al., (2014), and Rastogi (2014) note that DNA as a genetic material is composed of several numbers of genes with encoded information for synthesizing proteins or RNAs. Therefore, students' understanding of DNA molecule in posttest appeared deepening and sophisticated.

The second question "Are DNA strands identical? Explain" engendered students' understanding around the complementary nature of the DNA strands. The findings are revealed in Table 2.

Table 2
The Conception of Complementary Nature of DNA Strands

Category of Codes	**Response per Category (%)**	
	Pretest	**Posttest**
No. DNA strands are rather complimentary in nature due to the complimentary base pairs where adenine (A) pair up with Thymine (T) and guanine (G) pair up with cytosine (C) through hydrogen bonds	0	85
No. DNA strands are rather complimentary in nature due to the complimentary base pairs	0	4
No. DNA strands are rather not identical. Adenine (A) pair up with Thymine (T) and guanine (G) pair up with cytosine (C) through hydrogen bonds	0	7
No. DNA strands are rather not identical. Adenine (A) pair up with Thymine (T) / guanine (G) pair up with cytosine (C) through hydrogen bonds	1	4
No. DNA strands are not identical	7	0
Incorrect answer/ No response	92	0

In pretest, students' responses did not call out the names of nitrogenous bases let alone the concept of complementary nature of DNA strands. Majority (92 %) of the participants either spelled out non-normative ideas or did not respond to the question. Although 7 % of the participants had the idea that the DNA strands are not identical, they did not elaborate further in terms of complementary base-pairing. Therefore, students did not have the concept of DNA strands from the view of complementary base-pairs.

Conversely, the findings from the posttest implied ontological shift in participants' view of complementary nature of DNA strands. Majority (85 %) maintained that the DNA strands are not identical but complimentary in nature where nitrogenous base adenine (A) and guanine (G) pair up with the complimentary base thymine (T) and cytosine (C) respectively though hydrogen bonds. In the meantime, nearly 5 % of the participants opined the complementary nature of the DNA strands, although they did not specify the paring of nitrogenous bases A with T or G with C.

Nearly 15 % of the participants maintained that the DNA strands are not identical, though they did not proffered the explanation from complementary nature point of view. To support their point of view, 7 % of them spelled out the pairing of nitrogenous bases A with T and G with C, while other 4 % just mentioned the pairing of A with T or G with C. Scientifically, two strands of DNA are complimentary in nature. Schindler (2008) notes that two strands of DNA are complimentary by nature due to complimentary or Watson-Crick base pairs. Similary, Tshering (2016), Tshering et al. (2014), Rastogi (2014), and Schindler (2008) assert that the purine bases of one strand pairs with the pyrimidine bases of another strand or vice versa. Therefore, the views asserted by majority of the students after the intervention appeared matured or congruent to the scientific canonical notions.

The third questions "Write the sentence that includes nitrogenous base, nucleotides, and DNA strand" entailed the participants to connect nitrogenous base with nucleotides and the DNA strand. The findings are illustrated in Table 3.

Table 3
The Conception of Relationship amongst Nitrogenous Base, Nucleotides, and DNA Strands

Category of Codes	**Response per Category (%)**	
	Pretest	**Posttest**
Nitrogenous bases combine with sugar and phosphate groups and form nucleotides. The nucleotides join together to form long chain of DNA strands.	0	73
Nitrogenous bases combine with sugar. The nucleotides join together to form long chain of DNA strands.	0	5
Nitrogenous bases combine with phosphate groups. The nucleotides join together to form long chain of DNA strands.	0	3
Nitrogenous bases form nucleotides. The nucleotides join together to form long chain of DNA strands.	0	11
Nitrogenous bases combine with sugar and phosphate groups and form long chain of DNA strands.	0	6
Nitrogenous bases form long chain of DNA strands	19	2
Incorrect answer/ No response	81	0

In pretest, participants' responses did not present any cue of valid of understanding. Not surprisingly, majority (81 %) of the participants just posited either incorrect answer or did not answer at all. Although less than 20 % of the participants maintained that the nitrogenous bases form the long strands of DNA, they did not indicate how nitrogenous bases are related to nucleotides and nucleotides to DNA strands. As such, students' understanding of conceptual relationship amongst nitrogenous bases, nucleotides, and DNA strands appeared shallow and obscure. This is bound to happen given that the students in Bhutanese educational milieu do not learn the conceptual relationship amongst nitrogenous bases, nucleotides, and DNA until they are in 10th grade (MoE, 2012).

Conversely, many (73 %) participants' in posttest provided succinct point of view. They maintained that the nitrogenous bases combine with sugar and phosphate group and form nucleotides which in turn join together to form long strands of DNA. Moreover, 8 % of them also provided similar conception, although their point of view did not indicate either sugar or phosphate group. Meanwhile, 17 % of the participants also presented the similar understanding. However, their conception appeared somewhat truncated as their responses did not indicate either nucleotides or sugar and phosphate groups. In the overall, the findings demonstrate that the students have acquired the coherent understanding of the relationship existing amongst nitrogenous bases, nucleotides, and DNA strands. According to canonical scientific tones, the DNA strands contain nucleotides built out of deoxyribose sugar, a phosphate group, and one of the following nitrogenous bases: adenine, thymine, guanine, or cytosine (Nelson & Cox, 2000; Starr & Taggart, 1998; Suzuki, Griffith, Miller, Lewontin, & Gelbart, 1999). Similar results have been observed by Rotbain et al. (2006) in their study conducted to enhance 11th and 12th-grade students' understanding of DNA and its associated concepts through use of model-based lesson. However, their model-based learning unit has not only focused on the molecular structure of DNA but also the subcellular processes such as DNA replication, transcription, and translation.

The last question "Write a sentence that includes the concepts of DNA, protein, and cellular activities" informed the participants to explain the role of DNA in synthesising protein and link the concept with the genetic phenomena underlying across different levels of biological organisation. The findings are presented in Table 4.

Table 4

The Conception of DNA's Role and Genetic Phenomena

Category of Codes	**Response per Category (%)**	
	Pretest	**Posttest**
DNA contains codes for producing proteins. The proteins determine the structure and function of cells and the corresponding features of the organism	0	71
DNA contains codes for producing proteins	0	15
DNA contains information	0	13
DNA control cellular activities	89	1
Incorrect answer/ No response	11	0

As evident from their responses to the first question, participants in pretest had little or shallow understanding of DNA's role and genetic phenomena that span across different levels of biological organisation. Many (89 %) of participants explained the role of DNA from being a mere deterministic molecule or active particle that govern the cellular activities. In canonical notions, such understandings are incoherent and unsophisticated because they impede students' ability to construe how the information coded in DNA brings about the effect on the observable features. This results in incomplete or premature explanations of how genes are related to the perceptible features without presenting the underlining molecular or cellular mechanisms (Duncan, 2007; Duncan & Reiser, 2007). Meanwhile, rest of the students did not answer or just explicated irrelevant response.

In posttest, participants' responses appeared congruent to the scientific canonical notions. Many (71 %) of them had the view that DNA is genetic material that encodes instruction to make proteins, which in turn influence the structure and function of the corresponding biological phenomena. This finding indicates the conceptual change in participants' view of DNA molecule from being a mere deterministic molecule to the entity that contain instruction to specify the proteins. More so, the participants also had the idea of how genetic effect is expressed or rendered across different levels of biological organisation. In the overall, the finding indicates participants' robust understanding as Duncan, Rogat, and Yarden (2009) note that " students who are proficient in modern genetics … explain physical traits by incorporating molecular and cellular mechanisms into their explanations" (p. 667). Moreover, they also note that the "notion of productive instructions signals a move from a broad view of the genetic content (as specifying whole traits) to a more constrained view of the genetic content as specifying very small biological entities that carry out the functions in living things" (p. 665). In the meantime, 15 % of them stated DNA molecule as a genetic entity contain information to specify proteins, while remaining 13 % had the idea of DNA being a mere information molecule. The view of conceiving DNA as containing information is central to reasoning in genetics (Venville &Treagust, 1998). However, such view of DNA is still rudimentary because knowing that DNA carry information is only half the battle; one also needs to understand the content of the information—that DNA specify the amino acid sequence of proteins (Duncan & Reiser, 2007).

In the overall, the participants' conception of DNA molecule in pretest was far more constrained and shallow. However, after the intervention of physical model-based learning unit, the participants view of DNA molecule was rather matured and inline to the scientific canonical notions. There was an increase in the proportion of sophisticated responses indicating the correct understanding of DNA's structural and functional domains. This suggests that participants' conceptions of DNA molecules are influenced by the instruction, and that a greater number of participants demonstrated a more matured view of DNA after the instruction. Literature says that with carefully designed instruction, high school students can come to view DNA as productive instructions for proteins and to develop more robust understandings of proteins and their biological role, especially as it pertains to genetic phenomena (Duncan & Reiser 2007; Rogat & Krajcik 2006).

4. Conclusion

This study observed students' conceptual understanding of DNA molecule after implementing physical model-based learning unit. Thirty-eight 10th-grade students took part in the study. Data collected from pre-posttest DNA conceptual test was analysed based on the multiple coding cycle analysis.

Students' conception of DNA molecule in pretest was far more constrained and obscured. They had the rudimentary idea that DNA is a deoxyribonucleic acid that control cellular activities. However, after the implementing the physical model-based learning unit, their view of DNA molecule appeared more matured and sophisticated. They had the conception that DNA is a molecule which consists of two nucleotide strands twisted together (structure). The nucleotide sequence encodes instructions for synthesising proteins, where proteins in turn, bring effect about the corresponding biological organisations. Thefore, students' idea of DNA molecule presented in pre-posttest result indicates a learning trajectory from incoherent ideas to the intelligible realm of understanding. This presents the conjecture that students' conceptions of DNA molecule are influenced by the instruction of physical model-based learning unit.

4.1. Limitations

Though the physical model-based learning unit was implemented to enhance students' conceptual understanding of DNA molecule, the study is void of the finding that substantiates the statistical significance of the learning unit per se. More so, the findings of the study do not hold the merit to generalise to the larger audience considering the type of sampling method. The study lacked data from different sources as the data was collected merely using DNA conceptual test. The modeling activity of the DNA molecule, either the helical or linear model, did not lens into the concept of phosphodiester bond, covalent bonds, and other interacting entities. Further, the antiparallel nature and the double helix nature of DNA did not relate to its corresponding molecular or cellular processes such as replication or central dogma.

4.2. Educational Implications

The physical model-based learning unit can be used as an instruction to teach the concept of DNA molecule to high school students. It has the activity oriented from the physical aspects of DNA molecule to its molecular or chemical units. This type of instructional design may help the students to map two distinct ontological levels: physical aspects of DNA molecule and its molecular world. More so, the modeling activities of the learning unit would enable the students to construe the details of DNA molecule in concrete manner through visualization of the abstract concepts. Canonically, the models "reduces the information in DNA's chemical formula and simplifies the abstract information .... model is easy to manipulate, thus providing students with opportunities for constructing molecules and simulating processes on the molecular level" (Rotbain et al., 2006, p. 520). Therefore, "it is worthwhile to integrate model activities (physical) in the teaching of molecular genetics in high schools" (Rotbain et al., 2006, p. 521).

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Appendix A. DNA Extraction Protocol

DNA is found in every living tissue or cell. It is used in forensic science to track down the crime suspect, especially in the case of hit and run or murder. How is it possible? If the crime suspect has been identified, a sample of the suspect's DNA can be compared with the evidence collected from the crime scene. Based on the result of the comparison, things can be concluded whether the suspect has committed the crime or not.

Have you seen DNA in your life? How is DNA seen at the physical level? To observe DNA at the physical level, it needs to be isolated and extracted from the living tissues. One can extract DNA from fresh peas, fresh spinach, chicken liver, onion, or broccoli. How would you extract DNA from the onion peel? See the following procedures and extract DNA from the onion peel accordingly. Check if you have blender, table salt, detergent/soap solution, water, beaker, measuring cup and tea spoons, strainer, papaya juice, alcohol, test tube, and glass stirring rod in your class.

1. Get the onion peels chopped into small pieces and transfer them into the blender. Add one or two tea spoons of table salt into the blender. Add one cup of cold water into the blender and blend the mixture for at least 15 seconds until you get a thin soup of onion peel. Can you think of why onion peels are blended? What is the use of adding salt into the mixture?

2. Pour out the onion peel soup through a sieve or strainer into a beaker. Estimate the amount of onion peel soup contained in the beaker and add one-sixth of the liquid detergent or soap solution. Gently swirl the mixture for 5 to 10 minutes. Why is liquid detergent or soap solution added to the onion peel soup?

3. Pour the mixture into test tubes or small glass containers filling up to one-third of the capacity. Add papaya juice into each test tube containing the mixture. Gently stir the mixture. What is the role of papaya juice in this experiment?

4.Tilt your test tube and slowly pour the alcohol into the test tube down the side so that it forms a layer on top of the mixture. Pour the alcohol until you have it as equal as the amount of the mixture. You will notice alcohol floating on top forming two separate layers as it is lighter than the water. All of the grease and the protein broken up in the preceding steps will move to the bottom.

5.Gently stir the solution using a glass rod or a wooden stick for some time. You will observe a white mucous like a substance spooling around the rod or stick. What do you think is white mucous like a substance spooled around the rod or stick?

Appendix B. DNA Excerpt

Every living cell or tissue contains DNA. It is the blueprint of life. It was first discovered by **Friedrich Miescher** in 1869 during his study on while blood cells. The double helix structure of DNA molecule was discovered by Watson and Crick in 1953. Their landmark discovery of double helix structure proved DNA molecule's role in storing the information for growth and development of the living organism.

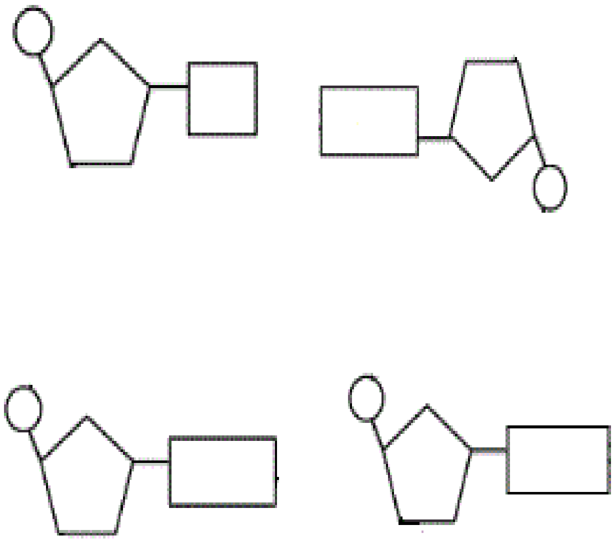
When DNA is extracted from the living tissues or cells, it comes in the form of a white mucous like a substance spooled around the rod or stick. Can you imagine the number of DNA molecules present in a spool? Perhaps, tens of thousands. How is each DNA molecule seen at the chemical level or molecular level? What constitute the DNA molecule?

A DNA molecule usually exist like a twisted ladder. This type of structure of a DNA molecule is known as a double helix structure. Each helix or strand contains several nucleotides, the building blocks of DNA. Each nucleotide is composed of three different components, such as sugar, phosphate groups, and nitrogen bases. The sugar and phosphate groups link the nucleotides together to form the DNA strand or a backbone. The nitrogenous bases such as Adenine (A), Thymine (T), Guanine (G) and Cytosine (C) of each strand joins with their complementary bases of another strand through hydrogen bonds. In the complementary base paring, base A bonds with T and base G with C.

Now let's make journey into the chemical composition of the DNA molecule by answering the questions given in the following activities:

The four nucleotides of a DNA molecule

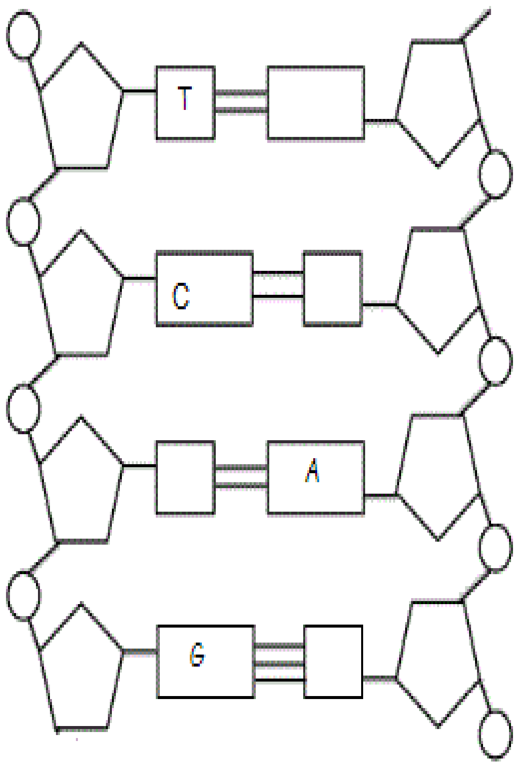
The figures on right side show the chemical structure of DNA's four nucleotides. Each nucleotide is made up of three components: deoxyribose sugar, phosphate groups and nitrogenous base.



1. Circle the deoxyribose sugar with black, in each of the nucleotide.
2. Circle the phosphate group with red in each of the nucleotide.
3. Circle each of the nitrogenous base in different colour.
4. Write the name of each component near the circle.
5. What are the similarities between the nucleotides?
6. What are the differences between the nucleotides?

The structure of a DNA molecule

The figure on the right side shows the chemical structure of a DNA molecule.



1. Circle the deoxyribose sugar with black, in each of the nucleotide.
2. Circle the phosphate group with red in each of the nucleotide.
3. Circle each of the nitrogenous base in different colour.
4. Circle each nucleotide in the DNA strand

The DNA molecule is made of two strands that are connected by hydrogen bonds.

1. Complete the boxes by filling up with the complementary base pairs.
2. Identify hydrogen bonds and draw an arrow pointing towards them.
3. Which nitrogenous bases complement each other?
4. Do you find any regularity between the types of complementary base pairs and the hydrogen bonds that connect them?
5. How many nucleotides are present in each DNA strand?

The structure of the DNA molecule is designed to store information. The DNA molecule stores information to specify the structure of protein molecule which in turn determine their own function. The function of the protein molecule determines the structure and function of the cells and the corresponding body organs. This is how the information stored in the DNA molecule brings about the effects upon the body traits. Think of how our eye colours are related to the information stored in the DNA molecules. The figure at the right side represents how the information stored in the DNA molecule is related to the overall structure and function of human heart through molecular and cellular mechanism.