AMERICAN UNIVERSITY OF BEIRUT

EFFECT OF SCIENCE AND ENGINEERING PRACTICES IN BIOLOGY ON STUDENTS ATTITUDES, ACHIEVEMENT AND ENGINEERING DESIGN SKILLS

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AN ABSTRACT OF THE THESIS OF

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Title: Effect of Using Scientific and Engineering Practices in Biology on Grade 8 Students' Achievement, Attitudes, and Engineering Design Skills.

Inquiry has long been used to promote students' conceptual understanding and meaningful construction of scientific knowledge. A number of researchers, however, claim that inquiry has its problems and does not always enhance students' attitudes and achievement in science (Alfieri et al., 2011). Moreover, inquiry teaching does not improve the learning for all students consistently. They also claim that there is no agreed upon definition of inquiry resulting in ineffective implementation of inquiry in science classrooms (Yager, 2012).

In response to the above controversy, the Next Generation Science Standards (NGSS) (2013) suggested that the implementation of science and engineering practices provides a better context to implement inquiry-type activities because these practices provide more explicit tools to implement meaningful and inquiry-oriented science activities which improve science learning. Schimdt (2014) has shown that the use of science practices provides an authentic approach to engage students in real-world science and reveal their misconceptions. A study conducted by Ercan and Sahin (2015) have also shown that the use of science and engineering practices improves students' achievement and attitudes towards science. Similarly, Cunningham and Carslen (2017) indicated that engineering design practices can improve children's understandings of scientific concepts and design skills. Consequently, the purpose of this study was to investigate the effect of using science and engineering practices in biology on students' achievement and attitudes toward biology. Hence, the study investigated the following questions: (a) What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' achievement in cellular biology? (b) What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' attitudes toward biology? (c) What are the effects of implementing scientific and engineering practices in teaching about cellular biology on eighth grade students' design skills?

The design of this study was quasi-experimental. Participants in this study were sixty-five eighth grade students in a K-12 international school in Lebanon. The classes were randomly assigned to a control and an experimental group. The experimental group was taught using science and engineering practices instruction presented in the K-12 Framework in the Next Generation Science Standards (NGSS) (2013). Meanwhile, participants in the control group received inquiry-based instruction throughout their activities. Both groups studied the cellular biology unit which was taught by the same teacher for five weeks. Data sources for the study included two cellular biology concept tests used as pre-tests and post-tests, two achievement tests, and a biology attitude scale (BAS) which was used to measure changes in students' attitudes toward biology in both groups. Moreover, students' written responses during an engineering design assessment were collected and analyzed in order to determine the proficiency level of students' engineering design skills. Finally, students' responses to interviews to gauge students' opinions about the teaching approaches were used in the study.

The results of the first and second concept tests showed that students in the experimental group achieved higher than students in the control group but the difference was not significant. Likewise, students' scores on the two biology achievement tests that were administered during the study did not show significant gains in achievement between both groups. However, results of the first achievement test showed that students' scores on the high cognitive level questions in the experimental group were significantly higher than the control group.

In depth analysis of the two-tier concept tests was carried out where the number of correct answers, reasons and both were computed for each test item. Results showed that the intervention improved the achievement of students in certain concepts but not in others indicating the possibility that a number of concepts included in the concept tests were abstract, which requires that teachers use strategies that help them to explain the concepts at the molecular level. Furthermore, the level of proficiency in design skills was higher in the experimental group than in the control group in assessing designs and explaining the designs functionality. Analysis of the results of the biology attitude scale showed that there were no significant differences in attitudes between the two groups. Finally, students showed positive but different opinions regarding the instructional approaches. Implications to practice as well as recommendations for further research are discussed in light of these findings.

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CHAPTER I

INTRODUCTION

Inquiry has long been advocated as a student-centered approach that promotes students' conceptual understanding and meaningful construction of scientific knowledge. Throughout history, "Inquiry" was viewed as a central term to characterize good science teaching and learning" (Anderson, 2002). The inquiry approach is believed to be important since it "promotes engagement, literacy and deep learning for all students especially reluctant ones" (Wilhelm & Wilhelm, 2010, p.39). Inquiry is recognized as a democratic type of learning because it involves continuous social interactions between communities of learners in an attempt to solve real-world problems. Throughout their involvement in inquiry-based approaches; students learn that they do not have to accept knowledge "imposed" by others but that they are active constructors of their own knowledge in ways that correctly fit the principles of disciplinary knowledge construction (Wilhelm & Wilhelm, 2010).

One of the major aims of science education since its foundation was to nurture students' inquiry skills, enhance their abilities in scientific inquiry and improve their reasoning and critical thinking skills in a scientific context. However, there has always been a conflict between the emphasis that should be placed on content development and the focus on science inquiry skills. A close focus on mere content has resulted in students having misconceptions about the nature of scientific inquiry and with the notion that science is purely an accumulation of factual knowledge (National Academy of Science, 2012).The most prominent theories that are aligned with inquiry teaching are social and cognitive constructivism: Piaget's theory of cognitive constructivism and Vygotsky's theory of social constructivism, both of which, according to Powell and Kalina (2009) support teaching inquiry and through inquiry because this teaching encourages students to construct their own knowledge based on meaningful and relevant prior knowledge.

1.1. Background

There are three different representations of inquiry in the National Science Education Standards (NSES, 1996): Scientific inquiry, inquiry teaching and inquiry learning. According to the NSES, scientific inquiry is defined as the “diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (p.23). On the other hand, the NSES defined inquiry learning as "an active learning process that the students are engaged in” (p.2). In addition, the NSES referred to inquiry teaching as “the activities of students in which they develop knowledge and understanding of scientific ideas and how scientists study the natural world” (p.23).

Although the majority of research claims that the use of inquiry is effective in enhancing student learning (Anderson, 2002; Sesen & Tarhan, 2011; Supasorn & Lordkam, 2014; Wilhelm & Wilhelm, 2010); a number of research studies investigating the effective use of inquiry to learn science argued that the use of inquiry in schools has its problems and does not always enhance students’ attitudes and achievement in science (e.g., Alfieri, Brooks, Aldrich & Tenenbaum, 2011; Clark, Kirschner & Sweller, 2012; Kalyuga, 2012).Moreover, other researchers claim that the assurance of educational transformations that inquiry was supposed to bring have not been recognized (e.g., Alfieri et al., 2011;Clark et al., 2012; Kalyuga, 2012). Furthermore, inquiry teaching has not improved learning for all students consistently (e.g., Alfieri et al., 2011; Chase, Pakhira & Stains, 2013; Clark et al., 2012; Kalyuga, 2012; Mastropieri, Scruggs & Butcher, 1997). For instance, Chase et al. (2013) reported that the use of Process-Oriented Guided Inquiry Learning (POGIL) in chemistry resulted in an insignificant impact on students' attitudes and achievement. Likewise, Baseya and Francis (2011) showed that the use of different inquiry teaching approaches did not influence positively students' attitudes toward and achievement in science. Moreover, inquiry teaching that aimed to improve the learning of all students has been found to be effective for certain types of student populations. In this regard, a number of studies reported that partially-guided or unguided inquiry is effective only for experienced students and not for inexperienced ones since it leads to cognitive overload (Alfieri et al., 2011; Clark et al., 2012; Kalyuga, 2012).Similarly, Mastropieri et al. (1997) showed that inquiry does not work with special education students.

Science curriculum and standards documents around the world emphasize using inquiry as a means and as an end when teaching science (Abd-El-Khalick et al., 2004). However, many research studies claim that the implementation of authentic inquiry in science classrooms is rarely accomplished (Jeanpierre, 2006; Forbes & Zint, 2011; Lakin & Wallace, 2015). In this regard, Lakin and Wallace (2015) report that many science teachers hold incomplete conceptions and misconceptions about scientific inquiry hence decreasing the positive impact of inquiry on student learning.

Research studies highlight the reasons for the lack of engagement of students and teachers in authentic inquiry and the major issues associated with this teaching approach (Chris, 2006; Forbes, Biggers & Zangori, 2013; Yager, 2012). Some teachers report that the implementation of inquiry requires time and resources which may result in an incomplete coverage of most state standards (Chris, 2006).Others attribute its ineffectiveness and absence of proper implementation to the absence of a uniform consensus regarding the definition and features that constitute classroom inquiry (Forbes et al., 2013; Yager, 2012). Hence, implementation of inquiry did not produce central developments in science classrooms.

In an attempt to resolve the issues behind the failure of inquiry to promote learning for all students, the science and engineering practices were developed in the K-12 Framework of the Next Generation Science Standards (NGSS) intended to better extend and explain the meaning of scientific inquiry (Bybee, 2011). According to Appendix F of the NGSS Lead

States (2013), engaging students in science practices helps them understand how scientific knowledge develops and value the wide range of approaches that are used to investigate and explain the real world. Similarly, engaging in the engineering practices provides students with the opportunity to understand the work of engineers, as well as the links between science and engineering. "It also helps students develop an understanding of the crosscutting concepts and disciplinary core ideas of science and engineering" (Appendix G, NGSS Lead States, 2013, p. 2). Moreover, it helps students solve major societal and environmental problems (Appendix I, NGSS Lead States, 2013). Hence, the practices of engineering and science are very similar except for the fact that "engineering design has a different purpose and product than scientific inquiry" (Appendix I, NGSS Lead States, 2013, p. 1). The NGSS identified the following eight science and engineering practices of the K-12 Framework which are essential for all students: Addressing questions (science) and defining problems (engineering); developing and using models; planning and running investigations; analyzing and interpreting data; utilizing mathematics and computational thinking; constructing explanations and designing solutions (engineering); engagement in argumentation from evidence and acquiring, evaluating and communicating information.

NGSS also provides new insights on how students can work on the integration among three dimensions of learning: Science and engineering practices; crosscutting concepts and disciplinary core ideas. According to appendix G of NGSS Lead states (2013); Crosscutting concepts are of significant importance because "they provide students with intellectual tools and connections across different disciplines and can enrich their application of practices and their understanding of core ideas" (p.233). Crosscutting concepts are also essential because they help students understand the core ideas in science and engineering which increase as students move higher in the educational ladder (NGSS Lead States, 2013, p.2). Examples of these crosscutting concepts include: Recognizing and analyzing patterns; identifying and explaining cause-effect relationships; using, constructing and explaining models; understanding structure and function; stability and change, and energy and matter.

The K-12 framework of the NGSS has described the progression of disciplinary core ideas in the grade band endpoints. These disciplinary core ideas describe the content that is covered at each grade band across K-12 (See appendix E of the paper entitled "Progressions within the NGSS Lead States, 2013). Moreover, the NGSS has identified the three core ideas of engineering design that do not follow a specific sequence: Defining and delimiting engineering problems; designing solutions to engineering problems and optimizing the design solution (Appendix I, NGSS Lead States, 2013). The NGSS emphasizes the integration of these three dimensions in students learning. Hence, each performance expectation must align with an applicable science or engineering practice, a core disciplinary idea and a cross cutting concept. This is because future assessments will no longer evaluate students' understanding of core ideas and their abilities to use science and engineering practices separately. Rather, these core ideas will be evaluated simultaneously to reveal that students can utilize their understanding to analyze the natural world through science practices and resolve major problems through engineering practices (Appendix F, NGSS Lead States, 2013).

Therefore, the science and engineering practices resolve a problem inherent in inquiry since the learning and doing processes in this teaching approach are separated (Bybee, 2011). An example of aligned *science practices*, disciplinary core ideas, performance expectations and crosscutting concepts in biology of the topic of energy and matter in organisms and ecosystems at the middle school level is presented in Figure 1.1. On the other hand, an example of aligned *engineering practices*, disciplinary core ideas, performance expectations and crosscutting concepts in biology on the topic of Molecules to Organisms: Structures and Processes at the same level is presented in Figure 1.2 (NGSS Lead States, 2013):

HS. Matter and Energy in Organisms and Ecosystems

Performance expectation. Students who demonstrate understanding can use a model to illustrate how photosynthesis transforms light energy into chemical energy.

Science practice

Developing and using models. Use a model based on evidence to illustrate the relationships between systems or between components of a system

Disciplinary core idea

Organization for matter and energy flow in organisms. The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.

Crosscutting concepts

Energy and matter. Changes of matter and energy in a system can be described in energy and matter flows into, out of, and within the system.

Figure 1.1. An Example of Aligned Science Practices, Disciplinary Core Ideas, Performance Expectations and Crosscutting Concepts in Biology.

HS. From Molecules to Organisms: Structures and Processes

Performance expectation. Students who demonstrate an understanding can analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Engineering practice

Defining Problems. Analyze complex real world problems and using constraints for successful solutions.

Disciplinary core idea

Defining and Delimiting Engineering Problems. Criteria and constraints also include satisfying any requirements set by society such as taking issues of risk mitigations into account and they should be quantified to the extent possible and state them in such a way that one can tell if a given design meet them

Crosscutting concepts

Influence of Science, Engineering and Technology on Society and the natural world. New technologies can have deep impacts on society and the environment including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology

Figure 1.2. An Example of Aligned Engineering Practices, Disciplinary Core Ideas, Performance Expectations and Crosscutting Concepts in Biology.

Recently, a small number of research studies have examined the assumption that implementing science and engineering practices in science classrooms leads to improved learning in science (Erduran & Dagher, 2014; Lakose, 2015; NGSS, 2013). For example, three empirical studies examined the effect of using science and engineering practices on the learning environment and students understanding (Chen & Steenhoek, 2014; Ercan & Sahin, 2015; Schimdt, 2014). Schimdt (2014) reported that the use of science practices to teach about fossils represented an authentic way to engage students in real world science since this approach allowed students to demonstrate their skills in creative problem solving and asking important questions. Moreover, this approach made it possible for the teacher to identify students' naïve conceptions about the topic. Similarly, Chen and Steenhoek (2014) demonstrated that engaging Grade 5 students in argumentative practices when studying the human body enhances their learning and understanding the "big idea "that the systems of the human body work together harmoniously. Ercan and Sahin (2015) also showed that the use of engineering design practices in physics with Grade 7 students led to high academic achievement and positive attitudes toward science. The three previous studies have shown that student achievement in science improved when the focus was on "scientific and engineering practices" rather than on inquiry in general. However, the results cannot be generalized because of the very small number of studies conducted on the topic. Therefore, it is reasonable to conduct a study that investigates the effectiveness of the implementation of scientific and engineering practices on students' achievement, attitudes and design skills in science.

1.2. Statement of the Problem

Studies have highlighted the positive impact of inquiry on most students' attitudes and achievement (e.g., Alfieri et al., 2011; Baseya & Francis, 2011; Chase et al.,2013; Clark et al., 2012; Kalyuga, 2012, Mastropieri et al., 1997). On the contrary, other studies (e.g., Alfieri et al.,2011; Baseya & Francis, 2011; Chase et al., 2013; Clark et al., 2012; Kalyuga, 2012, Mastropieri et al., 1997) found that inquiry does not work for all students and hence has minimal impact on their attitudes and achievement. Similarly, many studies have highlighted the issues associated with the definition of inquiry and its constituent instructional practices (Bybee, 2011; Forbes et al., 2013; Yager, 2012). Studies conducted in this area provided mixed results, which makes it difficult to generalize the overall impact of inquiry on science learning. Therefore, inquiry as currently implemented does not seem to yield to positive results for all students. On the other hand, several studies (e.g., Chen & Steenhoek, 2014; Ercan & Sahin, 2015; Erduran & Dagher, 2014; Lakose, 2015; Schimdt, 2014) have emphasized the need to implement scientific and engineering practices and their positive effect on student learning. To assist educators to implement science and engineering practices, Erduran and Dagher (2014) developed a heuristic that tackles the relationship between epistemic, cognitive and discursive practices of science and engineering. The above summary suggests that investigating the effectiveness of the implementation of scientific and engineering practices on students' achievement, attitudes toward and design skills in biology could be a productive research activity because this helps in defining the practices needed for students to experience authentic inquiry, are explicit enough to give the teacher the opportunity to focus on each of them, and may reduce memory overload because inquiry is broken down into specific manageable ideas.

1.3. Research Questions

In order to investigate the effectiveness of using scientific and engineering practices on students' attitudes toward and achievement in science in addition to design skills; this study specifically addressed the following research questions:

1. What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' achievement in cellular biology?
2. What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' attitudes toward biology?

3. What are the effects of implementing scientific and engineering practices in teaching about cellular biology on eighth grade students' design skills?

1.4. Rationale of the Study

The use of constructivism as an appropriate framework for inquiry teaching has been extensively studied in the science education literature (Anderson, 2002; Powell & Kalina, 2009). On the contrary, research has highlighted the unresolved issues and problems associated with inquiry (Anderson, 2002; Bybee, 2011; Forbes et al., 2013; Forbes & Zint, 2011; Lakin & Wallace, 2015; Yager, 2012).In addition, several studies have discussed the restricted positive effect of partially guided and unguided inquiry to experienced students while highlighting its negative impact on inexperienced students due to memory overload (e.g., Alfieri et al., 2011; Baseya & Francis, 2011; Chase et al., 2013; Clark et al., 2012; Kalyuga, 2012, Mastropieri et al., 1997). Furthermore, few studies have supported the use of science and engineering practices in classrooms as a way to resolve the issues associated with using inquiry (Chen & Steenbok, 2014; Erduran & Dagher, 2014; Ercan & Sahin, 2015; Schimdt, 2014, Lakose, 2015).

Attempts to resolve the issues of implementing inquiry in the classroom deal with the quality of the instructional strategies; consequently, a shift in the use of inquiry towards science and engineering practices has been taking place. This shift involves implementing effective instructional strategies that scaffold the science learning for diverse students. However, research that investigates the effectiveness of scientific and engineering practices has been very limited worldwide. Consequently, there is a need to conduct studies to investigate the effectiveness of science and engineering practices on students' achievement attitudes toward and design skills in science.

1.5. Significance

This study may help promote changes in the instructional practices that constitute “inquiry teaching” in science and may help to improve the definition of “inquiry teaching” by using science and engineering practices that provide explicit approaches that can be used to improve the quality of student learning. Furthermore, this study provides further insight on the effect of the implementation of scientific and engineering practices on students’ achievement, attitudes and design skills. It seeks to explore whether these practices improve the conceptual understanding of science through the acquisition of integrated knowledge and skills in addition to enhancing students’ attitudes toward science learning. The findings of this study might prompt educators to better plan their instructional practices in science classrooms to enhance students' conceptual understanding, attitudes and design skills. Results of this study may also stimulate other researchers to conduct additional studies in this field in an attempt to identify how to best implement these practices in science classrooms at other educational levels and scientific disciplines.

CHAPTER II

LITERATURE REVIEW

The twenty first century is dominated by the use of inquiry in our classrooms. Inquiry-based learning has become central in all disciplines of education. Teachers use inquiry in different ways across a variety of disciplines and for different goals in such a way that its consistent effectiveness for all students is taken for granted (Anderson, 2002; Sesen & Tarhan, 2011; Spronken-Smith, 2008; Supasorn & Lordkam, 2014; Wilhelm &Wilhelm, 2010). For instance, teachers use inquiry to promote meaningful learning, and to enhance student engagement and achievement. Moreover, several approaches are used in inquiry-based learning such as: problem-based learning, project work, case studies, workshops, and field work (Kahn & O'Rourke, 2004, as cited in Spronken-Smith, 2008, p.5). The use of inquiry has been found essential to promote critical thinking skills and meaningful construction of knowledge (Barrow; 2006, Keys & Bryan, 2001; Spronken-Smith, 2008).

While research results have shown that inquiry has not fulfilled its promises for all students consistently, some research studies have shown that inquiry-based learning has the potential to develop scientifically literate citizens and provide students with the necessary skills that would help them succeed in life (Lee et al., 2004 as cited in Spronken-Smith, 2008; McNeil & Krajcik, 2008).In the following section, I present a brief historical overview of the use of inquiry in science classrooms and discuss the promises of this instructional approach.

2.1. Inquiry Based Learning: History and Promises

The inclusion of inquiry in the K-12 science curriculum was recommended by John Dewey during the early years of the 20th century in an attempt to enhance students' learning outcomes (Barrow, 2006). Dewey recommended that teachers use inquiry through the application of the scientific method and by solving real-life problems. A few decades later, Dewey modified his earlier interpretation of the scientific method by incorporating the goal of reflective thinking. He also emphasized the fact that problems to be studied by students must be related to their own experiences (Barrow, 2006).

In the1950's, the National Science Foundation (NSF) in the USA funded the development of innovative science curricula in the USA which emphasized the science process skills which include: observing, classifying, inferring and controlling variables. A decade later, the teaching of science coupled with laboratory applications was presented as an attempt to improve students' understanding of scientific concepts. In this regard, Schwab (1960) stated that "science should be taught in a way that was to be consistent with the way modern science operates" (Barrow, 2006, p. 266). During the mid-1960's, Rutherford considered inquiry a combination of content and concepts that are to be discovered in their scientific context. In addition, the professional development for all science teachers in the history and philosophy of science was recommended (Barrow, 2006).

During the 1980's, the Project Synthesis report divided the student outcomes for inquiry into three categories: Science process skills, nature of scientific inquiry and general inquiry process. A decade later, the National Science Education Standards (NSES) considered inquiry as an "overarching goal of scientific literacy" (Barrow, 2006, p.268). At the end of the 20th century, five essential features of inquiry were identified by the NSES intended to "introduce students to many important aspects of science while helping them develop deeper knowledge of science concepts and processes" (Barrow, 2006, as cited in NRC 2000 p.27).These essential features are: Engaging students in scientifically oriented questions; developing and evaluating explanations to the scientifically oriented questions; developing evidence to address the scientifically oriented questions; evaluating explanations that reflect scientific understanding, communicating and justifying proposed explanations (Barrow, 2006).

The end of the 20th century saw an increased emphasis on the promotion of inquiry in science classrooms. For example, activities that investigate and analyze science questions were more emphasized than activities that demonstrate and verify science content and investigations that extend over a period of time were seen to replace the ones confined to one class period. Moreover, process skills in context were emphasized over process skills out of context. Also, multiple process skills were seen to replace individual process skills (Jeanpierre, 2006, as cited in NRC 1996 p.113).

The majority of research has claimed that the use of inquiry results in consistent and significant improvements in students' learning; hence, requiring educators to modify the curriculum and their instructional practices to be able to implement authentic inquiry in science classrooms (Anderson, 2002; Barrow, 2006; Keys & Bryan, 2001; Sesen &Tarhan, 2011; Supasorn & Lordkam, 2014; Wilhelm & Wilhelm, 2010). However, results of several empirical studies were not always in line with the promise and demonstrated that inquiry did not consistently improve the learning of all students (Alfieri, et al., 2011; Clark et al., 2012; Kalyuga, 2012).In the following section, I discuss the successes and failures of implementing inquiry as well as the reasons for the failure from various theoretical and practical perspectives.

2.2. Impact of Inquiry on Students' Attitudes and Achievement

Examining the majority of research about inquiry shows that it is effective in enhancing the learning of most students (Sesen & Tarhan, 2011; Supasorn & Lordkam, 2014; Wilhelm & Wilhelm, 2010). Wilhelm and Wilhelm (2010) reported the inquiry effects on reluctant students' achievements and attitudes towards science. Moreover, they found that inquiry teaching leads to higher student attendance, higher completion of formative assessments and better parental involvement. Several other researchers reported the effectiveness of inquiry (e.g. Lord, Shelly & Zimmerman, 2007; Sesen &Tarhan, 2011; Supasorn & Lordkam, 2014). More specifically, Supasorn and Lordkam (2014) examined the effect of five inquiry learning activities about separation of natural substances on middle school students’ achievement and attitudes towards chemistry. Outcomes of the study revealed that teaching chemistry through inquiry- based activities enhanced students' achievement as well as attitudes. Similarly, Sesen and Tarhan (2011) reported that inquiry-based laboratory activities lead to better conceptual understanding of electrochemistry and significantly improve secondary students' attitudes towards chemistry and laboratory skills. Similar results about the effectiveness of inquiry in improving student academic outcomes and attitudes were also highlighted by Lord et al. (2007) who conducted a study to examine the impact of using inquiry teaching in a college botany course. In this study, students were assigned to take an active role in the classroom in which they had to conduct their own investigations and prepare student-led discussions. Results showed that most students preferred the traditional teaching approach to inquiry at the beginning of the course. However, students gained more self-confidence over time in conducting their own investigations and showed significantly more positive attitudes towards the botany course. More importantly, approximately 90% of the students reported that they developed a better understanding of the nature of science (NOS) after conducting their own laboratory investigations and around 75% of the students said that they better retained the knowledge and understood the procedures involved after designing their own laboratory investigations.

Several research studies examining the effectiveness of inquiry revealed that inquiry does not always improve students' attitudes and achievement in science (Alfieri et al., 2011; Baseya & Francis, 2011; Chase et al., 2013; Clark et al., 2012; Kalyuga, 2012, Mastropieri et al., 1997). In an attempt to explore the effectiveness of inquiry on students' attitudes towards learning, Baseya and Francis (2011) examined the effect of Problem Based (PB) Inquiry versus Guided Inquiry (GI) on college students' attitudes toward science. Results showed that that four instructional factors which include: perceived excitement, difficulty of the material, level of guidance, and time efficiency had a significantly higher impact on students' attitudes than the laboratory style used by the teacher. Similarly, a study conducted with 200 students in the USA examined the impact of the implementation of Process-Oriented Guided Inquiry Learning (POGIL) on undergraduate students' achievement, retention, self-efficacy, and attitudes towards chemistry and the general learning environment. Results of the study indicated that the effect of inquiry ranged from little to no impact on students' attitudes. On the other hand, results revealed a significant positive impact on students' overall grades and retention of knowledge (Chase et al., 2013).

Another study conducted by Mastropieri et al. (1997) showed that inquiry does not work for special education students. The researchers investigated whether students with learning disabilities (LD) and mild mental retardation (MR) differed from normally achieving students concerning inductive thinking in an inquiry-learning task. The results showed that the majority of normally achieving students provided correct induction. On the contrary, only half of the students with LD and none of the students with MR induced correctly. Furthermore, around three-quarters of the students with LD and nearly all of the students with MR required significant amounts of coaching levels such as explicit instruction and direct explanation of rules.

Furthermore, several research studies showed that inquiry teaching does not improve the learning of all students consistently. With the aim of investigating the effectiveness of inquiry for certain types of students, Clark et al. (2012) presented a review of many empirical studies on the impact of different forms of instructional guidance on students' achievement in and attitudes towards science. The purpose of the review was to compare partially-guided inquiry and fully-guided inquiry. By considering the interactions between the long-term and short-term memory, the authors argue that instructional methods are influenced by the learners' prior knowledge in a specific domain, how learners use knowledge that is stored in long-term memory and how it is organized in short-term memory. The findings of this review showed that partially-guided inquiry and fully-guided inquiry are only effective for intermediate and experienced learners. In contrast, novices only benefit from explicit instruction and scaffolding. Examples of scaffolding include worked examples and corrective feedback. Similarly, a meta-analysis conducted by Kalyuga (2012) compared exploratory and direct forms of instruction with different levels of prior knowledge. Results of the reviewed studies revealed that exploratory learning environments were only effective for experienced learners. The research review by Clark et al. (2012) and the meta-analysis by Kalyuga (2012) reported the same reasons behind these findings. The researchers attributed the ineffectiveness of exploratory learning for inexperienced students to the cognitive overload that will in turn lead to poor learning outcomes. According to the cognitive load theory, inexperienced students cannot learn from extended periods of problem solving because they lack the prior-knowledge in the long- term memory since their short-term memory is limited when dealing with new information. However, experienced students do not benefit from explicit instruction because the long-term memory is distracted by the presence of prior-knowledge. Hence, this reduces the potential learning outcomes that could be achieved without guidance. The authors in the meta-analyses also emphasized the use of scaffolding as a way to bridge the gap between novice and advanced learners.

Alfieri et al. (2011) conducted two meta-analyses on the impacts of different forms of discovery learning on students' achievement in several domains. Discovery learning is a method of inquiry-based instruction in which the learner works independently by drawing on prior knowledge to discover the target information. The level of guidance in this approach can range from minimal to intensive depending on the assigned task. Studies included in the meta-analyses were divided into two categories: comparison between unassisted discovery learning versus direct instruction, comparison between enhanced and/or assisted discovery versus other types of instruction (direct instruction and unassisted discovery).The domains in this review included: Math, science, problem solving, computer skills, motor skills and verbal skills. Studies in the meta-analyses addressed four concerns. (a) Whether the process of discovering information needs to be taught to learners (b) The extent to which the discovery tasks should be structured (c) which types of tasks are considered within the discovery-learning environment (d) whether the working memory demands of discovery learning jeopardize the effectiveness of instruction. Participants in the studies include: young children, adolescents and adults. A total of 164 studies were used in the meta-analyses.

One-hundred and eight studies including 580 comparisons were reported in the first category. These studies investigated the impact of unassisted discovery versus direct instruction on students' learning. Generally, results of these studies showed that unassisted discovery does not benefit learning. More specifically, adolescents were shown to benefit significantly more from direct instruction than adults. On the other hand, children appeared to benefit the most from unassisted discovery.

In the second category (comparison between enhanced and/or assisted discovery versus other types of instruction), 56 studies including 360 comparisons were reviewed. Results showed that enhanced discovery methods are favored over other types of instruction. The authors in this meta-analyses concluded that enhanced discovery tasks lead to better learning outcomes for all age groups. More specifically, adults were shown to benefit from enhanced discovery more than children with adolescents benefiting the least from this approach.

2.3. Inquiry Teaching: Problems and Challenges

In an attempt to explore how inquiry is practiced in science classrooms, Jeanpierre (2006) conducted a survey with K-8 mathematics and science teachers to investigate their beliefs about their inquiry practices and the degree of alignment of these practices with full inquiry (Level 4). The results reported little evidence about the implementation of full inquiry in classrooms. Moreover, the results showed that the use of inquiry skills mostly occurred during guided-inquiry tasks. Similarly, Quigley, Marshall, Deaton, Cook & Padilla (2011) indicated that the most dominating level of inquiry performance among teachers is the level of guided inquiry (Level 2). Guided inquiry is the process by which students examine a given problem by designing their own procedures to find a solution.

In order to describe how inquiry is practiced in science classrooms, Asay and Orgill (2010) analyzed a number of articles published in *The Science Teacher* from 1998to 2007 with a focus on the analysis of the explicit evidence of the essential features of inquiry. Results showed that only few articles described full inquiry. In addition, gathering and analyzing information was reported as the most prominent feature of inquiry in science classrooms. Furthermore, results showed that that the majority of activities implemented in science classrooms were teacher-centered. Researchers in this study attributed these results to the lack of professional development for teachers, misconceptions held by teachers about scientific inquiry and time constraints. This is because "most teachers view inquiry more as a process rather than a vehicle for learning science content" (Assay & Orgill, 2010, p.1).

In a survey conducted with 1,222 K-12 mathematics and science teachers, Marshall, Horton, Igo and Switzer (2009) studied the impact of different variables (grade level, content area, level of support and self-efficacy for inquiry teaching) on (percentage of time that students are engaged in inquiry and perceived ideal percentage of instructional time that should be devoted to inquiry). Results revealed that K-12 teachers devoted only 37.3% of their instructional time to inquiry with elementary teachers reporting the highest percentage of time dedicated to inquiry-based practices. Moreover, elementary teachers reported more positive attitudes than middle and high school teachers towards inquiry-based practices. However, the majority of teachers believed in an ideal percentage of time devoted to inquiry that is significantly greater than their actual percentage of time spent on inquiry instruction. More importantly, results showed that elementary science teachers reported both an ideal and actual percentage of time on inquiry higher than math teachers. On the contrary, high school math teachers reported both an ideal and actual percentage of time on inquiry higher than science teachers. Researchers in this study reported that the heavy emphasis on inquiry standards in science achievement tests rather than procedural competencies as in the case of mathematics lead math teachers to outperform science teachers in inquiry instruction. Moreover, they attributed the significant difference in inquiry instruction between high school teachers and other groups of teachers to the lack of pedagogical content knowledge (PCK) and professional development.

Quigley et al. (2011) conducted a literature review to examine the challenges faced by teachers during the implementation of inquiry. The four challenges identified in this review were the following: (a) How can the quality of inquiry implemented in science classrooms be measured? (b) How can teachers use discourse to encourage effective inquiry-based learning? (c) How can we help teachers view inquiry and science content as two aspects of the same goal? (d) How can we help teachers learn to manage an effective inquiry classroom? The researchers indicated that the quality of inquiry can be improved through the use of the Electronic Quality of Inquiry Protocol (EQUIP) which provides a valid and reliable tool for measuring the quality of inquiry in classrooms. The tool is focused on four major constructs: instruction, curriculum, assessment and discourse. However, researchers reported that improvement in the quality of inquiry requires changes in instructional practices. The support necessary for the instructional transformations includes professional development and curricular and administrative changes. To address the second challenge, two effective discourse techniques: Providing feedback and follow-up information to improve the quality of inquiry-based learning were reported in the reviewed studies. In addition, the researchers attributed the third problem to the teachers' misconceptions about standards and their own experiences in science courses. This is because most teachers view standards as sequential topics to be covered. In order to resolve the third challenge, the researchers recommended combining inquiry, content, and critical reasoning skills, engaging students in evidence-based explanations, and developing appropriate assessments. These ways can also help students recognize inquiry process and science content as two different aspects of the same goal. The same challenge was also reported by Bybee (2011). In order to manage classroom inquiry more effectively, the authors recommended building solid and practical boundaries for guiding classroom interactions, creating strong relationships in a respectful environment, and setting high expectations for students.

Forbes et al. (2013) conducted a study to investigate the essential features of inquiry and scientific practices in elementary classrooms. The researchers collected data using the Practices of Science Observation Protocol (P-SOP) which provides a valid and reliable tool to measure the quality of inquiry. Data was collected from 124 videos recorded during K-5 science lessons. Results of the study showed that engaging students in scientific questions and giving priority to evidence are the most prevalent features in elementary science classrooms. However, lower scores were reported for the three explanations-related features: communication of evidence-based explanations, scientific practices of explanation, discussion and metacognition on reasoning. The findings were attributed to the lack of professional development, quality of curriculum materials and the absence of a uniform agreement regarding the definition of classroom inquiry which is defined differently for different people (Anderson, 2002; Yager, 2012). Similarly, the same challenge regarding the definition of inquiry was reported by Yager (2012).

In conclusion, the reviewed literature provides strong evidence that inquiry can improve learning even though there are studies which showed that inquiry does not work for all students, especially for students with special needs .However, more focus on defining the practices needed for students to experience authentic inquiry should be made.

2.4. Towards a Shift to Science and Engineering Practices

Many research studies examined the use of inquiry in the classroom and its effect on students' learning, attitudes and motivation with a number of studies showing no significant effect on students' achievement and attitudes. However, the claim made for the existence of science and engineering practices developed by the Next Generation Science Standards (NGSS) that benefits students learning is put forward in the literature with little empirical evidence on its success. Consequently, there has been an emerging body of research that began to investigate the effectiveness of science and engineering practices rather than inquiry skills. In this part of the review, I present several studies that focus on the effect of science and engineering practices on students' learning.

Schmidt (2014) examined the effect of using fossils with grade 8 students to teach NGSS science and engineering practices. Engaging students with fossils provided them with the opportunity to understand science and engineering practices. The lesson included watching a slide show of the teachers' field trip and students were asked to identify examples of the practices used. These practices included: Asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in arguments; communicating and evaluating information.

At the beginning of the study, students found difficulty connecting the practices together while watching the slide show. However, this challenge disappeared after allocating most of the time for reflections on the collected data. Results showed that engaging activities related to fossils turned to be a meaningful way to teach students real-world science. In addition, students were able to demonstrate creative problem solving, ask important questions, and correct their misconceptions.

Higbee (2014) studied the effect of using social media with grade 6 students to teach NGSS science and engineering practices. In this study, the teacher - who was also the researcher- shared the fossils field trip with students through the school Instagram account where she posted daily pictures of the field trip. The practices included: asking questions, engaging in arguments from evidence, and communicating and evaluating information. Results showed that engaging students in social media is effective for teaching science and engineering practices since this approach promoted open discussions about fossils, biodiversity and Science, Technology, Engineering and Mathematics (STEM) careers.

In order to illustrate how science and engineering practices affect students' learning, Chen and Steenhoek (2014) conducted a study with one fifth-grade class to examine the effect of argumentation, a core science and engineering practice, on students' learning of science through a lesson on the human body. A negotiation model composed of six phases was used as a theoretical framework to implement the study. The six phases included: Creating a testable question, conducting an investigation cooperatively, constructing an argument in groups, negotiating arguments publicly, consulting the experts, and writing and reflecting individually. Data was collected using students reflections and a rubric to score students arguments according to the learning outcomes of the unit and standards of the district. The results indicated that students developed deeper conceptual understanding, critical thinking skills, and scientific literacy. The study, though conducted with a very limited number of students, reveals interesting results that encourage the use of argumentation with larger numbers of students.

McNeill and Pimentel (2009) conducted a study to examine the impact of argumentation on students' science learning. Participants in this study included three teachers and their students, all from the same large urban district school in England. Data was collected using videotapes on all of the teachers' lessons. The data analysis examined both the argument structure and the dialogic interactions using Toulmin's model of argumentation. Results showed that the majority of the students' discourse included evidence and reasoning to justify claims. However, only one teacher's classroom was characterized by student-to-student interactions with students explicitly supporting and refuting each other's ideas. Researchers concluded that the teachers' instructional practices were closely associated with the students' potential gains. In particular, teachers who use open-ended questions improved students' argumentation skills and attitudes towards science. The results of the study emphasized the close relationship between effective teaching practices and the use of argumentation in improving science learning.

Zangori and Forbes (2014) conducted a study to examine the impact of the construction of scientific explanations, a core science practice, on students' learning of science. The unit selected for the study was about plant growth and development entitled " Structures of Life". Participants in the study included 59 third-grade students from three different classrooms with their corresponding teachers. Prior to the study, the teachers participated in a three-year professional development program designed to support elementary teachers to improve students' engagement in science practices. Data was collected from multiple sources and included: videotaped observations, teacher interviews, and students' written samples. The researchers concluded that teachers' instructional practices and conceptions of scientific explanations influence students' construction of scientific explanations. Specifically, teachers who emphasized a single “correct explanation” rarely supported their students’ explanation-construction. However, teachers who emphasized the importance of multiple "correct explanations" improved students' explanation skills. The results of the study highlighted a close link between teachers' conceptions about scientific explanations, effective instructional practices, and students' formulations of scientific explanations.

In order to examine the effect of modeling on students' learning, Hokayem and Schwarz (2014) conducted a study with 34 fifth-grade students in a school in USA. The unit selected for this study was about evaporation and condensation and was taught over a period of 8 weeks. Data was collected using written assessments, videotapes, and interviews. Results of the study indicated that students made significant progress in constructing models that convey unobservable characteristics of molecular processes. In addition, students succeeded in using models as tools aligned with evidence in order to predict other phenomena. Similarly, Krajcik and Merritt (2012) highlighted that engaging students in scientific modeling improves students' understanding of big ideas and explanation of phenomena aligned with evidence.

Ercan and Sahin (2015) conducted a study to examine the effect of using science and engineering practices on students' achievement and attitudes towards science. Participants in this study included 30 seventh grade students studying a unit on force and motion. Data collected from achievement tests indicated that students made significant gains in scientific knowledge and engineering skills. Moreover, interviews, field notes, and student journals revealed an increased level of motivation towards physics. Similarly, Cunningham and Carslen (2017) indicated that engineering design practices could improve children’s understandings of scientific concepts and design skills. Daugherty (2012) also reported that engaging students in engineering design practices may help increase student interest in science (as cited in Lakose, 2015).

Several researchers conducted a study to further examine the effect of engineering practices more specifically on students' achievement and attitudes towards science. Participants in this study included elementary students from grades 1 to 5 studying a unit on water. Data collected from the written assessments indicated that students demonstrated better understanding and science and engineering concepts. Moreover, results from the attitude Likert scales revealed that Engineering in Elementary (EiE) students showed more positive attitudes towards science and engineering and an increased level of interest in engineering careers than those in the control group. These students also showed a significantly higher performance on science and engineering assessments (Lachapelle, Phandis, Jocz & Cunningham 2012, as cited in Lakose, 2015 p. 16-17).

Hammack, Ivey, Utley and High (2015) conducted a study to investigate the effect of an engineering camp on students' perceptions of engineering and technology. Participants in this study included 19 middle school students participating in a one week engineering summer camp. Results showed that engaging students in such programs have a positive impact on their conceptions of technology and engineering. However, there was no clear evidence about the components of the camp that lead to this change.

Levy (2013) conducted a study to investigate the impact of design-based learning on young students' conceptions of water flow. Participants in this study included 30 five to six year old students in an urban school in Israel. Students in the experimental group were asked to build water pipe systems. Data was collected using pre-tests, post-tests and end of session interviews. Results of this study indicated that the involvement of students in the building process significantly increase the students' understanding of the physical rules. Moreover, it increases the students' potential to coordinate two physical rules together.

2.5. Summary

In the past, advocates of science education argued that teachers need to implement inquiry in order to have a positive impact on students' learning. Over the last decades, educational research on the use of inquiry has shown that implementation of inquiry teaching has increased significantly (Anderson, 2002; Sesen & Tarhan, 2011; Supasorn & Lordkam, 2014; Wilhelm & Wilhelm, 2010). More specifically, research studies revealed a remarkable increase in professional development programs that assist teachers in the implementation of inquiry in the classroom (Capps, Crawford & Constas, 2012). Despite this increase in the support of inquiry in science classroom, there is some evidence that inquiry has its problems and does not always enhance students ' attitudes and achievement in science (Alfieri et al., 2011; Clark et al., 2012; Kalyuga, 2012).

Many researchers have investigated the effectiveness of inquiry in science classrooms with the majority of studies showing increased students' achievement and more positive attitudes (Anderson, 2002; Sesen & Tarhan, 2011;Supasorn & Lordkam, 2014; Wilhelm & Wilhelm, 2010).However, several studies have shown that inquiry does not work for all students, especially for those with special needs (Alfieri et al., 2011, Mastropieri et al., 1997), the fact that resulted in limited progress in research and application of authentic inquiry in science classrooms (Jeanpierre, 2006; Forbes & Zint, 2011; Lakin & Wallace, 2015). It has been found that there is a lack of understanding of the meaning and essential features of inquiry and this has been recognized by the inappropriate implementation of authentic inquiry in science classrooms (Forbes et al., 2013; Yager, 2012).As a consequence, the vast school implementations of inquiry ended up with some failures despite all the reform efforts that aimed to improve the quality of this approach (Alfieri et al., 2011; Barrow, 2006, Clark et al., 2012; Kalyuga, 2012).

Clearly stated in many research articles, one of the main reasons for the failure of inquiry in classrooms is the absence of a unified and coherent definition of inquiry (Yager, 2012). As a result of the need for an extended and clear definition for inquiry that leads to effective learning, researchers of the NGSS developed science and engineering practices in the K-12 framework that are intended to improve the definition of inquiry and enhance all students' achievement and attitudes towards science consistently. The NGSS Lead states (2013) emphasize that the framework has the possibility of promoting better fruitful applications of authentic inquiry and research results. Such a framework, NGSS highlights, would allow researchers to identify the features of inquiry by breaking them into specific manageable ideas that could be productive for science learning. This framework may resolve practical and theoretical issues associated with inquiry and help in the appropriate implementation of authentic inquiry in science classrooms.

CHAPTER III

METHODOLOGY

3.1. Research Design

As indicated earlier, the purpose of this study was to further investigate the effect of implementation of science and engineering practices on intermediate level students' achievement, attitudes and design skills during the teaching of cellular biology. The research design was quasi-experimental. However, it was not possible to randomly assign students into control and experimental groups because the school performs its own assignment process based on the following criteria: Arabic level; type of track (Lebanese/ American) and students' academic achievement. The school requires students of mixed abilities to study in the same classroom. Hence, the classes were randomly assigned to control and experimental in order to improve the validity of the study.

3.2. Participants

Subjects in this study were 8th grade students in a K-12 secular, non-profit, independent American and International preparatory school in Beirut. The school serves an international multi-cultural student body. It aims to build active and collaborative members of society who are qualified for admission to selective universities. The school implements the AERO (American Education Reaches Out) curriculum sponsored by the U.S. State Department Office of overseas schools and uses various instructional resources to accomplish the goals of the program. It uses English as the language of instruction in science. The school was selected for its convenience and accessibility in addition to the availability of the facilities required for implementing the study. As indicated earlier, the study involved grade 8 students who were randomly assigned into two sections. The study took place during the biology classes. The students take five sessions of biology per a six-day cycle where each cycle consists of six school days.

A male teacher who has 20 years of teaching experience taught the experimental and control groups with approximately 32 students in each. He usually implements various teaching approaches and is an expert in Next Generation Science Standards (NGSS) science and engineering practices. Prior to the intervention, the researcher further introduced the teacher to science and engineering practices instruction in a number of individual meetings. In these meetings, the teacher was more acquainted to the benzene ring heuristic of science and engineering practices (Erduran & Dagher, 2014) (Figure 3.1) and its various components. .The researcher explicitly explained this instructional approach and reminded the teacher that he must promote the practices of science and engineering design of the NGSS framework. The teacher was also asked to encourage students to present different models by emphasizing the social and cooperative aspects of science and engineering practices. The researcher then supplied the teacher with the intervention lesson plans. The teacher and the researcher met prior to each session and discussed the lesson plan to be implemented during the next class period. These meetings allowed the researcher to further monitor and assess any obstacles arising during the intervention. Moreover, the researcher attended all the classes to insure that the lessons are being implemented as planned.

The students were informed that they were going to participate in an experimental study. However, they were not informed to which group they will belong to (whether control or experimental). The researcher was aware about the ethical responsibility towards the students and ensured that the intervention is not intrusive during the study as per the requirements of the Institutional Research Board (IRB).

3.3. Intervention

Both groups were taught a 5 week unit (4 six-day cycles) on cellular biology. Every cycle included six school days with 6 blocks per day and each block consisting of 60 minutes. The unit included two chapters which were a major part of the grade 8 American Education Reach Out (AERO) curriculum. The topics covered included: cell structure and function and cellular transport. Due to the condensed AERO curriculum in grade 8, the teacher was always alert about the limited amount of time available to cover the entire curriculum. Hence, this study allowed both groups of students to cover the assigned curriculum within the allocated duration but through the implementation of different instructional approaches. The control group studied the content of the unit through the incorporation of interactive inquiry-based approaches. This implies that the students in the control group implemented the science process skills of the scientific method in addition to inquiry-based research to complete their activities. As for the experimental group students, the teacher taught the same content but implemented science and engineering practices of the NGSS aligned with the activities planned during the 7 blocks of the intervention.

3.3.1. Cognitive Teaching Theories

In order to understand how to enhance learning through the use of effective instructional strategies, one should examine how humans learn (Osborne, 2014). Consequently, it is important to understand how instructional strategies have been used to improve student learning in the area of science (Lee & Songer, 2004). In the following section, I discuss the Cognitive load theory that is recognized to be helpful in designing effective teaching strategies that improve learning.

For several decades, Sweller (1988) examined the instructional implications of a model of memory called the information processing model of memory. Based on this model, the working memory has a limited capacity and can only hold few chunks of information at the same time, the cognitive load theory suggests several mechanisms to reduce cognitive overload and overcome the restrictions on students' learning abilities and achievement. One of the most prominent mechanisms is scaffolding which includes the breaking down of a complex task into multiple simpler tasks to achieve the desired goal. In order to achieve this mechanism, the information processing model suggests the use of scaffolding strategies such as worked examples, feedback and modeling (Lee & Songer, 2004). These strategies reduce the "problem-space" and cognitive load leading to more effective learning. According to Newell and Simon (1972), problem space id defined as the gap between the current situation of the learner and the desired goal. The implementation of science and engineering practices plays a major role in this issue as they increase the capacity of the working memory and allow the transfer of knowledge. Moreover, science and engineering practices promote high-levels of thinking skills (Osborne, 2017).

Table 3.1. Elements that Constitute Inquiry Based Approach and NGSS Science and Engineering Practices

Element	Inquiry approach	NGSS Practices
Interactivity	Taught using interactive visual aids and animations.	
Content Learning	Taught using Student-centered approaches.	
Lab Activities	Incorporate Science process skills of the essential features of inquiry.	Incorporate NGSS Science and engineering design practices of NGSS (2013).
Class Activities	Incorporate guided inquiry-based research.	Incorporate Science Practices of NGSS (2013).
Teacher Guidance	☑	☑
Inquiry Levels of activities (On Heron's Scale)	Level 0 to 2	☒
Articulation	☑	☑
Reflection	☑	☑
Collaborative Learning	☑	☑

3.3.2. Comparison between Structured Scientific Inquiry and NGSS Science and Engineering Practices

According to NSES (1996) scientific inquiry refers to a multifaceted activity that involves five essential features which include the following: Conducting observations and posing questions; using multiple resources to check what is already known in light of scientific evidence; gathering, analyzing and interpreting data; proposing answers, explanations and predictions and communicating the results. In this study, a structured inquiry approach was used. Following the structured scientific inquiry approach, any student at any age with basic scientific literacy may be able to apply the instructions provided and obtain correct data without necessarily critically thinking about his/her work. This is because structured inquiry does not emphasize the physical, cognitive and social aspects required to engage students in a scientific investigation (NGSS, 2013). By implementing structured scientific inquiry approaches, students sometimes do not have the freedom to test their own thinking because the scientific question and the procedure needed to answer the question are provided. However, the science and engineering practices are practices that enhance the students' conceptual understanding and skills because "they scaffold students in the specific forms of disciplinary literacy required" (Osborne, 2014, p.188). The science and engineering practices develop students' cognitive and meta-cognitive processes (Osborne, 2014) allowing them to reflect and articulate their thoughts. Using engineering design practices, students possess the freedom to design and test their own product as they are only provided with the problem to be solved, criteria of success and limitations (refer to Table 3.2).

Since decades, instructional practices that can help students succeed in cognitive tasks have been described by many educators who proposed several definitions for these practices. Micheals, Shouse and Shweingruber (2008) generally defined practices as "doing something repeatedly in order to become proficient" (as cited in Bybee, 2011, p. 38). The National Research Council (NRC) (2012) proposed the term science and engineering practices that was used by the NGSS (2013). These practices involve the following: Asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematical and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence and obtaining evaluating and communicating information. Bybee (2011) described science and engineering practices as both instructional strategies and learning outcomes. Osborne (2014) suggested that science and engineering practices provide support for higher order thinking skills such as critique and evaluation because they are based on the" understanding of how humans learn" .

Table 3.2. Comparison between Structured Scientific Inquiry and NGSS Science and Engineering Practices

Scientific inquiry	NGSS Science and Engineering Practices
1. Involves five essential features (e.g. making observations and posing questions; investigating multiple resources to see what aligns with experimental evidence; gathering and interpreting data).	1. Involve seven practices (e.g. asking questions and defining problems; modeling; constructing explanations and designing solutions; obtaining and evaluating information).
2. Does not emphasize the social, cognitive and physical aspects required to engage in scientific investigations.	2. Emphasizes the social, cognitive and physical aspects required to engage scientific investigations.
3. Lack scaffolding instructional strategies.	3. Include scaffolding instructional strategies (e.g. modeling, argumentation).
4. Does not include engineering design practices.	4. Include engineering design practices (e.g. defining problems and designing solutions).
5. Certain levels of inquiry do not provide students with freedom to test their own thinking (e.g. structured or confirmation inquiry).	5. Provides students with the freedom to test their own thinking (e.g. engineering and design).
6. Do not support students' metacognitive processes.	6. Support students' metacognitive processes and develop higher order skills.

3.3.3. Common Elements between Inquiry-based Approach and NGSS Practices

- ***Interactivity.*** The cognitive load theory suggests that the content presented must contain high levels of interactivity through simple ways that do not require complex processing by students. In addition, students were actively engaged with their peers and their teacher (Mayer & Moreno, 2010).
- ***Content Learning.*** Student-centered learning is very important in science. During this approach, students show better academic achievement and improve their social skills (Asoodeh, Asoodeh & Zarepour, 2012). Researchers have indicated that student-centered approaches enhance the students' attitudes towards learning and increase academic achievement (Asoodeh et al., 2012; Hinosolango & Dinagsao, 2014).
- ***Teacher Guidance.*** Coaching and guidance are very important in student-centered environments especially when they involve science learning. During such settings, the teacher provides hints, instructions and feedback (Mayer, 2004). Researchers argue that an unguided approach leads to cognitive overload because it ignores the structures of the human cognitive architecture (Kirschner, Sweller, & Clark, 2006). According to the Cognitive Apprenticeship Model (Wilson & Cole, 1996), teachers should monitor students' performance in order to prevent them from deviating away from the assigned goal, while leaving them enough space for exploration and problem solving. This aligns with NGSS practices because they scaffold learning of students and hence allowing them to examine their strengths and weaknesses.
- ***Articulation.*** In science learning, students are required to think about their actions and to give reasons for their answers, collected data and strategies (Litowitz, 2009). In this study, students' thoughts and actions are articulated in personal notebooks and worksheets within the activities in order to improve their scientific reasoning (Litowitz, 2009).

- ***Reflection.*** Students look back over their work to complete a certain task and analyze their performance (Iiyoshi, Hannafin & Yang, 2005).Reflection is very similar to articulation except for the fact that it points back to previous tasks. During the study, students reflected on their practices and explanations to improve the quality of their science learning (Baird, Peter, Gunston & White, 1991).
- ***Collaborative Learning.*** Collaborative learning is very important in a student-centered setting. During such setting students discuss their own ideas, challenge their accuracy and verbalize them (Litowitz, 2009). In this regard, collaborative learning has been shown to promote student engagement and achievement. Hence, students in the study completed all the activities in their assigned groups.

3.3.4. Elements that Constitute Inquiry Approach only

- ***Inquiry Levels.*** Based on the idea that unguided inquiry was shown to demote students abilities since it creates a cognitive overload (Kirshner et al., 2006), in this study, guidance was provided when students were implementing both approaches (science and engineering practices and inquiry) in both groups (through the lab instruction sheet, peers and teacher for example). However, the difference is with the presented activities. In this regard, Herron (1971) developed a model that classifies inquiry activities on a scale that ranges from level 0 (confirmation /verification) to level 3 (open/unguided inquiry). Two of the inquiry approach activities provided represented inquiry levels 0 to 2 while one activity represented inquiry-based research. On the other hand, NGSS science and engineering practices activities did not represent any inquiry level but it is rather an enriched instructional strategy that scaffolds the science learning for students.
- ***Science Process Skills versus NGSS Practices.*** In this study, students in the control group used the science process skills needed for scientific inquiry to complete their lab

activities. These science process skills include: Observation, classification, measurement, communication, inference and prediction. On the contrary, students in the experimental group used the NGSS science and engineering practices in their activities. These practices incorporate: modeling, argumentation, defining problems and designing solutions.

- ***Guided inquiry based research versus NGSS Science Practices*****.** In this study, students in the control group used guided inquiry-based research to complete their class activities or worksheets. The students' research was guided by the teacher and authorized research sites were recommended. On the contrary, students in the experimental group used NGSS science practices in their activities

Tables 3.3 and 3.4 present an overview of the instructional activities of experimental and control groups respectively The intervention used in this study is further described in details in the following section. The lesson plans of all the sessions for both groups during the intervention period are attached in Appendices A and B.

Table 3.3. Overview of the Experimental Group Instructional Activities

Session	Duration (minutes)	Activity	Summary
1	15	NGSS practices Introduction	Students in groups developed their notions of science practices.
	20	Diffusion Activity	Students situated their notions of NGSS through this activity.
	15	Benzene Ring Heuristic (BRH)	Students linked the ideas of the activity to the BRH.
2,3	60	Cellular Organelles	Students researched about different types of cells and cellular organelles based on questions provided by the teacher.
4,5	60	Cell Analogy Activity	Students worked in groups of two to complete the activity in order to learn about the function of different cellular organelles.
6,7	60	Passive cellular transport	Passive transport was explained using notes and animations.
8	60	Active Transport	Active transport was explained using notes and animations.
9	40	Red Rover Activity and	Students completed a modeling activity and reflected on it.
	20	Quiz	
10,11,12	60	Cellular Transport Design Project	Students designed and tested a setup that would either demonstrate diffusion or Osmosis

Table 3.4. Overview of the Control Group Instructional Activities

Session	Duration (minutes)	Activity	Summary
1	15	Inquiry & Scientific Method	Students in groups developed their notions of the scientific method
	20	Diffusion activity	Students situated their notions of inquiry and scientific method through this activity and their notions were discussed.
	15	Scientific method	Students linked the ideas of the activity to the scientific method.
2,3	60	Cellular Organelles	Students researched about different types of cells and cellular organelles based on questions provided by the teacher.
4,5	60	Cellular Organelles worksheets	Students completed two worksheets through research which were then corrected and discussed.
6,7	60	Passive cellular transport	Passive transport was explained using notes and animations.
8	60	Active Transport	Active transport was explained using notes and animations.
9	60	Cellular Transport Worksheet	Students completed a worksheet through research which was corrected and discussed.
10	60	Potato Osmosis Activity	Students completed the activity and answered lab questions
	20	Potato Osmosis Activity	Students recorded their results and lab questions were discussed.
11	40	Osmosis & Bag Activity	Students collected and recorded their results and answered the lab questions
	35	Osmosis bag activity	The lab questions were discussed.
12	25	Cellular Transport Worksheet	Correction and discussion of worksheet

3.3.5. Instruction of Science and Engineering Practices

As mentioned earlier, the intervention consisted of 7 blocks (60 minutes each). In the first block, the experimental group students who were not previously exposed to any science and engineering practices instruction were introduced to NGSS science and engineering practices. The students explored the components of science and engineering practices and their meaning based on the Benzene Ring Heuristic of science practices. The teacher first implemented a brief activity related to diffusion which was developed by the teacher and the researcher. The activity was then reviewed by another science teacher to ensure its validity. In this brainstorming activity, students reflected on their different perceptions of science and engineering practices. Students in groups were asked to develop a list of their initial notions of science and engineering practices, construct concept maps to link their ideas and presented them briefly. During the presentations, the teacher highlighted the common perceptions of science and engineering practices based on the students' responses. The teacher then defined science and engineering practices and related them to the field of science. The teacher explained that the idea that we hold about the scientific method as the only linear process for the establishment of scientific facts is no longer acceptable by the science education community. In science and engineering, ideas are established through the use of NGSS science and engineering practices in a circular sequence represented by the model of the Benzene Ring Heuristic (BRH). These practices capture the fragmented social, cognitive and physical complexities of the scientific method. In general, science and engineering practices can help solve the problems of inquiry-based learning by bringing all the aspects of the scientific method together (Bybee, 2011; NGSS Lead States, 2013; Yager, 2012).

The teacher then explicitly introduced the Benzene Ring Heuristic (BRH) of the NGSS science and engineering practices through an activity similar to the one conducted by Krajcik and Merritt (2012). The BRH was chosen to be introduced explicitly because it is a significant starting point for intermediate level students to get acquainted with the components of science and engineering practices. According to Erduran and Dagher (2014), the Benzene Ring Heuristic (2014) allows students to better understand the components of science and engineering practices and the relationship between them. In this activity, students were asked to draw and label a model related to the diffusion of blue ink in hot and cold water. They were then asked to work individually in an attempt to draw pictures that illustrate what happens between the ink particles and water particles in different situations. Afterwards, the teacher distributed a copy of BRH and asked the students to link the ideas in the heuristic to the Diffusion of Ink activity that they had just conducted. They then discussed their pictures in order to evaluate the adequacy of each other's models before a whole classroom discussion was conducted. The aim of these discussions was for students to actually realize that a single activity might engage them in several components of science and engineering practices integrated in a non-specific and iterative sequence. They also realized that the use of the step by step scientific method could be "invalid" at certain times. The teacher guided the discussions in such a way that the various components of science and engineering practices got revealed. He then illustrated a structured diagram (Figure 3.1) which provides a sample of NGSS science and engineering practices developed during the classroom activities of the discussed activity and filled in the various components of science and engineering practices to familiarize the students with the meanings of the scientific terms in the BRH. The teacher elaborated that the BRH allows scientists and engineers to solve real-life problems or design solutions; it is a well-structured and coherent model. The various components of science and engineering practices were defined and the students received a handout **(Appendix C)** that includes information describing each component along with a diagram of BRH.

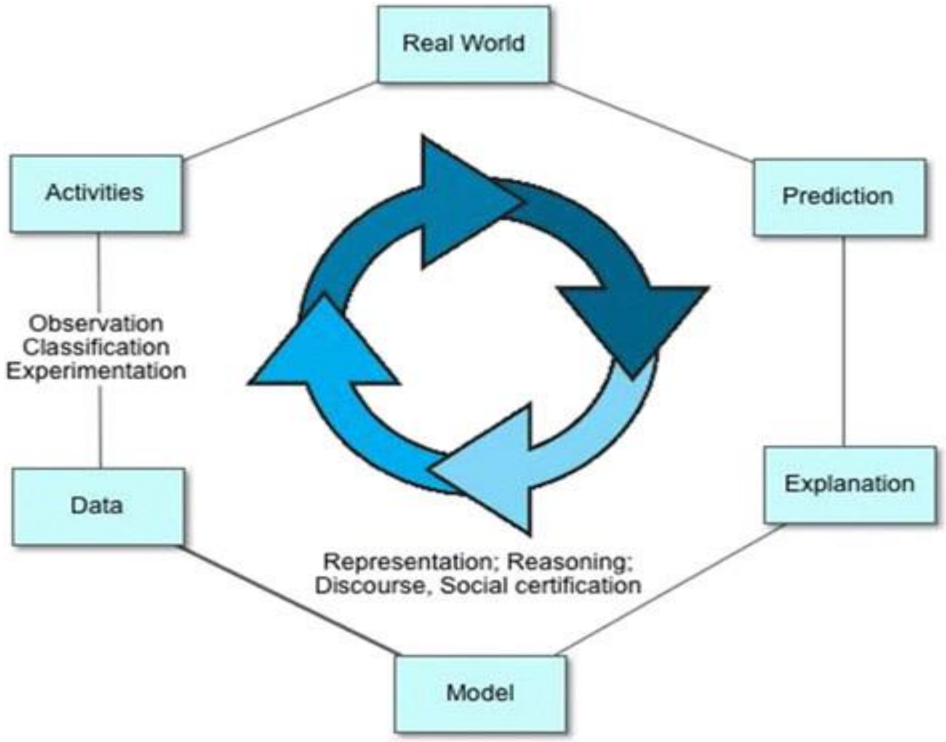

Figure 3.1. Components of Science and Engineering Practices within the Benzene Ring Heuristic (BRH).

3.3.6. Science and Engineering Practices in Cellular Biology

In the next seven sessions, the students utilized the acquired science and engineering practices in the classroom activities to learn about cellular biology. The cellular biology activities selected for the science and engineering practices sessions included: Analogy cell project, cellular transport modeling activity and selectively permeable membrane design project (osmosis). This is because these activities were related to the content of the unit and the students had the required pre-requisite content knowledge that allowed them to engage successfully in activities related to cellular biology.

In these science and engineering practices sessions, the teacher used individual students writing frames and whole classroom discussions as teaching strategies. The writing frames consisted of questions that were specifically developed for each cellular biology activity. These questions were mental prompts that assisted students in engaging in science practices. According to Dawson and Venville (2010), the use of writing frames in science classrooms can enhance students' thinking and writing skills. After the students completed their group activities, they were engaged in a whole classroom discussion. A whole classroom discussion strategy was adopted because it allows the students to express their views and be aware of the science and engineering practices in which they are engaged. The whole classroom discussion allowed the teacher greater control over the raised and discussed ideas and issues.

The students read the instructions of the cellular biology activities or engineering design projects and completed them in groups. During engineering design projects, students had to engage in research in order to design their models. By completing the activity and answering the questions, the students were engaged in certain components of science and engineering practices. For instance, students were asked to make a claim based on evidence and reasoning from the generated data. They were also asked to construct and review models to represent their data; check its accuracy and make predictions. Moreover, they were asked to persuade others with different opinions. This helped the students further explore explicitly the different science and engineering practices components in relation to the questions raised during the activity. The teacher encouraged the students to share, articulate and review the accuracy of their responses. He also built on the students views by providing and requesting further evidence and justification. The teacher encouraged students to respond to each other by acting as a facilitator.

3.4. Variables

The independent variable of the study was the instructional approach (NGSS science and engineering practices or guided inquiry) while the dependent variables were students' achievement in biology, students' attitudes toward biology, and students' design skills in biology.

- ***Students' achievement in biology.*** In learning science, students do not need mere acquisition of facts but rather should be able to analyze scientific problems and transfer them to new situations (BouJaoude, 2010). Specifically, science learners should be able to analyze, apply, synthesize and evaluate information. Consequently, measuring students' achievement took the above characteristics into consideration.
- ***Students' attitudes towards science.*** The examination of students' attitudes towards science has been a central topic in science education for the past decades (Osborne, Simon & Collins, 2003). The importance of this topic is a result of the notable decline of young students' and adolescents interest in school science (Potvin & Hasni, 2014; Weiss & Fortus, 2011). Similarly, research studies have highlighted a significant decrease in the number of students pursuing science-related careers (Bevins, Brodie & Brodie, 2005). For the past decades, researchers in science education have attempted to provide a clear definition of attitude (Osborne et al., 2003). Many research studies have included a number of components that constitute to the definition of attitudes towards science (e.g. Brown, 1976). Some of these components, as per Osborne et al. (2003, p. 1054) include the following: the perception of the science teacher; anxiety toward science; the value of science; self-esteem related to science; motivation towards science; enjoyment of science; achievement in science and fear of failure in science courses.
- ***Students' engineering design skills.*** The link between science and engineering has been an essential topic in the recent years (NGSS, 2013). The importance of this topic is due to the lack of the necessary engineering and science skills among students (Bevins et al., 2005). Specifically, science learners should be able to analyze problems, explore solutions, and transfer them into real-life situations (BouJaoude, 2010).

3.5. Data Collection

The following section provides a description of the instruments that were used for data collection. These instruments include: concepts knowledge tests, achievement tests, engineering design task assessment, biology attitude scale, and individual interviews. This is followed by the data analysis section.

3.5.1. Instruments

- ***Cellular biology concept tests.*** Two concept tests which include two-tier multiple choice questions were used as pre and post tests for each of the cellular biology units **(Appendix D).** The first two-tier concept test was used as a pre-test and a post-test for the chapter on cellular organelles. Before the study, students completed this test which aimed to assess their formal knowledge and misconceptions about cells and cellular organelles. The test was also administered at the end of the study in order to test for differences before and after the study. The test has been developed and validated based on students' misconceptions, propositional knowledge and target concepts. (Hailegebriel & Menkir**,** 2014**).** The test was reviewed and modified by two science teachers to ensure that it is appropriate for grade 8 students. The final version of the test consisted of 5 items and the highest possible score that could be achieved was 15.

  The second two-tier concept test was used as a pre and post-test for the chapter on cellular transport. Before the study, students completed this test which aimed to assess students' formal knowledge and misconceptions about cellular transport. The test was also administered at the end of the study in order to test for differences before and after the study. The test was developed and validated based on students' misconceptions, propositional knowledge and target concepts. The same test was extensively used by researchers to detect students' misconceptions in cellular transport (Odom, 1995). The alpha coefficient for this test was 0.74 indicating that it is reliable. The test was reviewed and modified by two science teachers to ensure that it is appropriate for grade 8 students. The final version of the test consisted of 10 items and the highest possible score that could be achieved was 30. .

Scoring students' performance of the concepts tests took into consideration the responses to the two tiers of the questions (Selecting the answer in the first tier and selecting the reason in the second tier. The system was as follows:

- Correct choice, correct reason gets 3 points
- Correct choice, wrong reason: 1 point
- Wrong choice-wrong reason and wrong choice and correct reason: 0 points

- ***Cellular biology achievement tests*.** An instrument for assessing the students' achievement was developed for the purpose of the study **(Appendix E).** Two tests were developed, one for each chapter. The aim of these tests was to assess students' achievement at the end of the chapters. The researcher who is a biology teacher developed the test and two other science teachers (with more than 10 years of teaching experience) assessed the test's validity making sure that it accurately measures what is supposed to measure**.** The teachers and the researcher then met to discuss the tests items and agree on them. Each test included multiple choice questions, open-ended questions, and real-life problems. The highest possible score that could be achieved on the first and second achievement test was 34. The number of test items in the first achievement test was 28 while the number of test items in the second achievement test was 31. These test items were completely aligned with the chapter objectives that were defined in terms of both content and cognitive level and were distributed over various levels of blooms taxonomy. Osborne (2012) claimed that NGSS practices require higher order skills of synthesis and evaluation. Hence, students' achievement at higher levels of Bloom's taxonomy might improve as a result of the implementation of these practices. In order to ensure that the tests were aligned with the curriculum, they were analyzed using tables of specifications **(Appendix H).** In addition, a comprehensive description of the six levels of blooms taxonomy was used to analyze the cognitive levels of the items **(Appendix G).**

- ***Biology attitude scale (BAS).*** Students' attitudes towards biology were measured using the BAS adapted from Prokop, Tuncer and Chudá (2007). Most of the questions in the scale were developed by Salta and Tzougraki (2004) (as cited in Prokop et al., 2007 p.289). The scale was revised by three biology teachers in order to ensure validity. In addition, the reliability (alpha coefficient) for this scale is 0.87, indicating that it is reliable. The scale used in this study consisted of 30 items in the form of positive and negative statements. Students responded to these statements in a five point Likert where A is 'strongly agree', B 'agree ', C 'not sure', D 'disagree', and E 'strongly disagree'. The scale consisted of six subscales: an interest scale, teacher scale, difficulty scale, future career scale, importance scale and equipment scale The interest and importance scales consisted of 7 items each while the difficulty and career scales consisted of 5 items each. Moreover, the equipment and teacher scales consisted of 3 items each. The items in the scale were almost equally divided between negative and positive statements. The interest domain measured the students' interest toward biology lessons while the career domain measured the students' attitude on the importance of biology for their future career. The difficulty domain measured the students' perceptions about the difficulty of the subject while the importance domain measured the students' perceptions regarding the importance of biology in real-life. In addition, the teacher subscale measured the students' attitudes toward the biology teacher while the equipment subscale measured the students' attitude regarding the use of biology equipment. The highest possible score for the interest and importance subscales was 35 while that of the difficulty and career domain subscale was 25. Moreover, the highest possible score for the equipment and teacher domain subscale was 15. Hence, the highest possible score that could be achieved was 150. **(Appendix I and J).**

- ***Individual interviews.*** Individual semi-structured interviews **(Appendix K)** were conducted with the experimental and control group students who answered ten open-ended questions at the end of the study. Forty nine students were randomly selected from the control and experimental group (23 from the control group and 26 from the experimental group) in order to conduct the interviews. The interview questions aimed to investigate students' attitudes toward using science and engineering practices and the structured inquiry approach at the end of the study.
- ***Design Task Assessment (DTA).*** An instrument for assessing students' design skills was developed for the purpose of the study **(Appendix L)**. The teacher who is an expert in NGSS and the researcher who is also a biology teacher developed the assessment. Afterwards, a science education professor assessed the assessment's validity to insure that it accurately measures what it is supposed to measure.
- ***Design Task Rubric (DTR)***. A rubric aligned with the elements of the design task assessment was developed for the purpose of the study **(Appendix M).** The researcher, science education professor and a science teacher assessed the rubric's validity to insure that it accurately measures what it is supposed to measure. According to this rubric, students' responses on engineering design questions were classified as proficient (level 3), developing (level 2), beginner (level 1), and novice (level 0). A response was categorized as proficient (level 3) in question 1a and 1b when the participant gave a correct scientific answer supported by a correct scientific justification. In addition, a response was categorized as proficient (level 3) in question

1c when the student correctly stated the name of the molecule by considering the factors that have the potential to influence membrane permeability(e.g. particle size and concentration gradient).On the other hand, a response was categorized as proficient (level 3) in question 2 when the drawn design correctly tested the membrane permeability for the two tested substances and took into consideration the stated constraints. Moreover, a response was categorized as proficient (level 3) in question 3 when it explained the membrane permeability based on two substance-indicator reactions and by providing justifications that are aligned with the design.

A response was categorized as developing (level 2) in question 1a when the student stated the correct scientific term demonstrated by the given setup without providing a clear justification. However, a response was categorized as developing (level 2) in question 1b when the student provided a correct scientific justification related to concentration gradient without providing a correct answer. Moreover, a response was categorized as developing (level 2) in question 1c when the student gave the names of the molecules without taking into consideration the concentration gradient as a factor that affects membrane permeability. A response was categorized as developing (level 2) in question 2 when the drawn design tested the membrane permeability for the two tested substances without taking into consideration the stated constraints. Finally, a response was categorized as developing (level 2) in question 3 when it explains the membrane permeability based on two-substance indicator reactions without providing a justification aligned with the drawn design.

A response was categorized as beginner (level 1) in question 1a when the student stated the correct scientific term demonstrated by the given setup without providing a correct justification. Similarly, a response was categorized as beginner (level 1) in question 1b when the student provided a correct answer without providing a correct justification. Moreover, a response was categorized as beginner (level 1) in question 1c when the student stated the names of the molecules without taking into consideration the concentration gradient or the particle size as factors that affect membrane permeability. On the other hand, a response was categorized as beginner (level 1) in question 2 when the drawn design tested the membrane permeability for the one tested substance. In addition, a response was categorized as beginner (level 1) in question 3 it explained the membrane permeability based on one substance-indicator reaction without providing a justification aligned with the design.

A response was categorized as novice (level 0) in question 1a when the student did not provide a correct answer and a correct justification or both are missing. Similarly, a response was categorized as novice (level 0) in question 1b when the student did not provide a correct answer and justification or both are missing. A response was categorized as novice (level 0) in question 2 when the drawn design did not test the membrane permeability for any of the tested substances while a response was categorized as novice (level 0) in question 3 when it did not provide any relevant justification related to substance-indicator reactions and did not provide a justification aligned with the design. The theoretical framework of the assessment and its different elements are discussed below.

3.5.2. Theoretical Framework of the Engineering design Task Assessment

The engineering design task assessment used in this study was developed using the elements of the science and engineering design framework of NGSS (2013). The teacher and the researcher had several meetings to agree on the items that need to be used in the assessment. In the next section, I provide a concise description of the items of the science engineering design task assessment that align with the elements of NGSS science and engineering design.

- ***Assessment of Given Design.*** In order to understand how to promote deep learning effectively through the use of the science and engineering design approach, students should learn how to analyze and interpret data; engage in argumentation from evidence, in addition to acquiring, evaluating and communicating scientific information (NGSS, 2013). Moreover, students are required to implement these practices in the items corresponding to this criterion in order to improve their science and engineering skills. More specifically, students are asked to analyze the cellular transport process demonstrated by a given setup, justify their answers based on evidence, and write their answers using accurate scientific terms.

- ***Functionality of Design.*** Engineering design projects play an important role in promoting deep understanding, critical thinking, and engineering skills. The engineering design framework states that students need to learn how to create engineering design solutions based on certain criteria and constraints for the problem. Consequently, students are asked to implement this component of design by creating a functional setup which best demonstrates diffusion or osmosis using the materials provided by taking the given constraints and criteria into consideration. This requires the students to schematize only one labeled setup that tests the permeability for two tested substances, protein and starch, using relevant materials.
- ***Explanation of Design Testing.*** In order to determine the functionality of a created design, students should be able to "optimize their design solution by testing and refining final design" (NGSS Lead States, Appendix I, 2013, p.2). Moreover, they must learn how to construct scientific explanations based on their designs (NGSS, 2013). Consequently, students are asked to explain the testing of membrane permeability based on two substance-indicator reactions i.e. one for each tested substance. This also requires the students to align their justifications provided with the drawn design.

3.6. Data Analysis

In order to answer the first research question (What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' achievement in cellular biology?), students' achievement was measured by using the scores on the Biology Concept Tests and Biology Achievement Tests. A univariate analysis of covariance (Univariate ANCOVA) was conducted on the data from the two *Biology Concept Tests* with the pre-test as a covariate and post-test as dependent variable in order to determine if differences existed between the control group and experimental group. A significance level of 0.05 was used. This method eliminates any factors affecting students' achievement other than the intervention in order to accurately evaluate the effect of the intervention on achievement. Moreover, an independent samples t-test was conducted on the data of the two achievement tests for the control and experimental groups. A significance level of 0.05 was used. An independent samples t-test was also conducted on the different cognitive level questions of blooms taxonomy in the two achievement tests to determine if any significant difference exists between the control and experimental groups. A significance level of 0.1 was used.

Concerning the second research question: (What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' attitudes toward biology?) Students' responses on the *Biology Attitude Scale* adapted from Prokop, Tuncer and Chudá (2007) were analyzed by using a univariate analysis of covariance (Univariate ANCOVA) with the pre-test as a covariate and post-test as dependent variable in order to determine if differences existed between the control group and experimental group. A significance level of 0.05 was used. This method eliminates any factors affecting students' attitudes other than the intervention in order to accurately evaluate the effect of the intervention on attitudes. In addition, interview students' responses on interview questions were analyzed verbatim to generate data trends regarding the attitudes of students. More specifically, students' responses on interview questions transcribed verbatim, were coded based on the interview questions and were assigned into categories to identify trends. In order to ensure reliability, the results of analyzing the interview transcripts were checked by the university researcher in order to identify any differences and reach a consensus regarding these differences.

Concerning the third research question: What are the effects of implementing scientific and engineering practices in teaching about cellular biology on eighth grade students' engineering design skills? Students' engineering design skills were measured qualitatively by using their responses on the engineering design task assessment. Students' responses for each of the engineering design elements were evaluated by using the Design Task Rubric (DTR). According to the rubric, students' responses on engineering design questions were classified as proficient (level 3), developing (level 2), beginner (level 1), and novice (level 0). Afterwards, the number of students in each level was computed in all items for both groups.

CHAPTER IV

RESULTS

Results of the study are provided in two sections. The first section presents the quantitative results acquired from analyzing the two cellular biology concept tests, the two cellular biology achievement tests, Biology Attitude Scale and the Design Task Assessment. The second section presents results acquired from analyzing qualitative data from the interviews.

4.1. Quantitative Results

The total number of students in this study was 65 with 32 students in the control group and 33 in the experimental group. Students' ages ranged between 13 and 14. Among the 65 participants of this study, 33 were male students and 32 were female students. Table 4.1 presents the number of students who participated in this study by gender and group type.

Table 4.1. Percentages and Numbers of Students Distributed by Group Type and Gender

Group	**Male**	**Percentage (%)**	**Female**	**Percentage (%)**	**Total**
Control Group	18	56.25	14	43.75	32
Experimental Group	15	45.45	18	54.55	33
Total	33	50.80	32	49.20	65

Students in both experimental and control groups were administered the two concept tests which were used as pre-tests and post-tests. In addition, both groups were administered the same pre-attitude and post-attitude scale during the study. The means and standard deviations of the two pre-post concept tests and the pre-post attitude scale were calculated and the results are presented in Table 4.2.

The maximum score that could be achieved on the first concept test is 15. Students in the control group scored higher on the pre-test (mean=8.66) than students in the experimental group (mean=7.52). Students' scores in both groups were almost the same in the post-tests (mean=11.94 in the control group and mean=11.85 in the experimental group). However, the standard deviation in the post-test of the control group (2.71) was less than the experimental group (3.34) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group.

Similarly, the maximum score that could be achieved on the second concept test is 30, students in the control group scored slightly higher on the pre-test (mean=9.72) than students in the experimental group (mean=9.00). Students' scores in both groups increased in the second post-tests (mean=18.06 in the control group and mean=17.55 in the experimental group). However, the standard deviation in the post-test of the experimental group (5.77) was higher than the control group (5.36) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group.

The maximum score that could be achieved on the pre-post attitude scale is 150. Students' pre-attitude scores in both groups were almost the same (mean=92.63 for the control group and mean=92.61 for the experimental group). However, the students' post-attitude scores almost remained the same in the control group (mean=92.26) while it decreased in the experimental (mean=90.42). Moreover, the standard deviation in the post-attitude scores of the control group is (19.68) which is less than that of the experimental group (19.90) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values.

Two dependent samples t-tests were conducted to find out if the posttest scores were significantly higher than the pretest score on both concept tests in the control and experimental groups. Results showed that in both situations, the post test scores were significantly higher than the pre-test scores (P=0.00< 0.05).

Table 4.2. Means and Standard Deviations of the Pre-Post Attitude Scales and the Two Pre-Post Concept Tests of the Control and Experimental Groups

Group	Pre-attitude		Post-attitude		Concept Test 1		Post-Concept Test 1		Concept Test 2		Post-Concept Test 2	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Control Group	92.63	14.89	92.26	19.68	8.66	3.76	11.94	2.71	9.72	4.76	18.06*	5.36
Experimental Group	92.61	19.76	90.42	19.90	7.52	3.79	11.85	3.34	9.00	4.84	17.55*	5.77

- P=0.00< 0.05

The maximum score that could be achieved on the first achievement test is 34. Students' scores on the first achievement for both groups were almost the same (mean=23.58 in the control group and mean=23.83 for the experimental group). However, the standard deviation in the first achievement test of the control group (4.40) was less than the experimental group (5.55) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. The maximum score that could be achieved on the second achievement test is 34, students' scores on the second achievement test in the experimental group (mean=21.37) were higher than students' scores in the control group (mean=20.30). However, the standard deviation in the second achievement test of the control group (4.67) was slightly less than the experimental group (4.84) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. As can be seen in Table 4.3 students' scores in both the experimental and control groups were relatively low reaching a maximum of 23.83 on the achievement tests. It is worth noting that the averages of the achievement tests in both groups ranged between 60% and 70%, relatively low but acceptable scores for both groups (if the passing grade is 60%), indicating that they benefited equally from being involved in structured inquiry or science and engineering practices activities.

Concerning the scores on the low cognitive level questions, the maximum score that could be achieved on the knowledge level questions of the first achievement test is 14.5. Students' scores on the knowledge level questions of the first achievement test were higher in the control group (mean=10.68) than the experimental group (mean=10.22).However, the standard deviation in the knowledge level questions of the first achievement test in the control group (2.00) was less than the experimental group (2.71) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. The maximum score that could be achieved on the comprehension level questions of the first achievement test is 8.5. Students' scores on the comprehension level questions of the first achievement test were higher in the control group (mean=7.05) than the experimental group (mean=6.78).However, the standard deviation in the comprehension level questions of the first achievement test in the control group (1.26) was less than the experimental group (1.45) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group.

The maximum score that could be achieved on the knowledge level questions of the second achievement test is 9.0. Students' scores on the knowledge level questions of the second achievement test were slightly higher in the experimental group (mean=6.68) than the control group (mean=6.52). However, the standard deviation in the knowledge level questions of the second achievement test in the control group (1.54) was slightly less than the experimental group (1.56) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. In addition, the maximum score that could be achieved on the comprehension level questions of the second achievement test is 11.5. Students' scores on the comprehension level questions of the experimental group (mean=7.21) in the second achievement test were higher than the control group (mean=6.81). However, the standard deviation in the comprehension level questions of the second achievement test in the control group (2.19) was less than the experimental group (2.37) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. These results are presented in Table 4.3.

Table 4.3. Means and Standard Deviations of the Two Achievement and the low levels of Blooms Taxonomy in the Two Achievement Tests of the Control and Experimental Groups

Group	**Achievement 1**		**Achievement 2**		**Knowledge 1**		**Comp. 1**		**Knowledge 2**		**Comp. 2**	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Control Group	23.58	4.40	20.30	4.67	10.68	2.00	7.05	1.26	6.52	1.54	6.81	2.19
Experimental Group	23.83	5.55	21.37	4.84	10.22	2.71	6.78	1.45	6.68	1.56	7.21	2.37

- Comp: Comprehension Level

Concerning the scores on the high cognitive level questions, the maximum score that could be achieved on the application level questions of the first achievement test is 3.5. Students' scores on the application level questions of the first achievement test in both groups were almost the same (mean=2.21 in the control group and mean=2.06 for the experimental group). However, the standard deviation in the application level questions of the first achievement test in the control group (0.79) was less than the experimental group (0.90) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group

In addition, the maximum score that could be achieved on the analysis level questions of the first achievement test is 5. Students' scores on the analysis level questions of the first achievement test in the experimental group (mean=3.15) were higher than the control group (mean=2.54). However, the standard deviation in the analysis level questions of the first achievement test in the control group (1.36) were less than the experimental group (1.50) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group

Moreover, the maximum score that could be achieved on the synthesis level questions of the first achievement test is 1. Students' scores on the synthesis level questions of the first achievement test in the experimental group (mean=0.40) were higher than the control group (mean=0.23). However, the standard deviation of the synthesis level questions of the first achievement test in the experimental group (0.29) was less than the control group (0.31) indicating that students' scores in the experimental group were closer to the mean and spread over a narrower range of values than the control group. The maximum score that could be achieved on the evaluation level questions of the first achievement test is 1.5. Students' scores on the evaluation level questions of the first achievement test in the experimental group (mean=1.22) were higher than the control group (mean=0.87).However, the standard deviation in the evaluation level questions of the first achievement test in the experimental group (0.42) was less than the control group (0.66) indicating that students' scores in the experimental group were closer to the mean and spread over a narrower range of values than the control group .These results are presented in Table 4.4.

Table 4.4. Means and Standard Deviations of the High Levels of Blooms Taxonomy in the First Achievement Test of the Control and Experimental Groups

Group	Application 1		Analysis 1		Synthesis 1		Evaluation 1	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Control Group	2.21	0.79	2.54	1.36	0.23	0.31	0.87	0.66
Experimental Group	2.06	0.90	3.15	1.50	0.40	0.29	1.22	0.42

Concerning the scores on high cognitive level questions, the maximum score that could be achieved on the application level questions of the second achievement test is 3.5. Students' scores on the application level questions of the second achievement test in the experimental group (mean=1.87) were higher than the control group (mean=1.57). However, the standard deviation in the application level questions of the second achievement test in the control group (0.74) was less than the experimental group (0.93) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group.

Moreover, the maximum score that could be achieved on the analysis level questions of the second achievement test is 7. Students' scores on the analysis level questions of the second achievement test in the experimental group (mean=3.52) were higher than the control group (mean=3.27). However, the standard deviation in the application level questions of the second achievement test in the control group (1.36) was less than the experimental group (1.45) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group.

In addition, the maximum score that could be achieved on the synthesis level questions of the second achievement test is 1.5. Students' scores on the synthesis level questions in the second achievement test in both groups were almost the same (mean=1.20 in the control group and mean=1.14 for the experimental group). Similarly, the standard deviation in the synthesis level questions of the second achievement test in the control group (0.55) was the same as experimental group (0.55) indicating that students' scores in the control group were equally deviated from the mean and over the same range of values. Similarly, the maximum score that could be achieved on the evaluation level questions of the second achievement test is 1.5.Students' scores on the evaluation level questions of the second achievement test in the experimental group (mean=0.95) were slightly higher than the control group (mean=0.93). However, the standard deviation in the evaluation level questions of the second achievement test in the experimental group (0.49) was less than the control group (0.54) indicating that students' scores in the experimental group were closer to the mean and spread over a narrower range of values than the experimental group. These results are presented in Table 4.5.

The maximum score that could be achieved on the low cognitive level questions of the first achievement test is 23. Students' scores on the low cognitive level questions in the first achievement test in the control group (mean=17.73) were higher than the experimental group (mean=17.00). However, the standard deviation in the low cognitive level questions of the first achievement test in the control group (2.80) was less than the experimental group (3.88) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. In contrast, the maximum score that could be achieved on the low cognitive level questions of the second achievement test is 20.5. Students' scores on the low cognitive level questions in the second achievement test in the experimental group (mean=13.89) were higher than the control group (mean=13.33). However, the standard deviation in the low level questions of the second achievement test in the experimental group (2.97) was slightly less than the control group (3.10) indicating that students' scores in the experimental group were closer to the mean and spread over a narrower range of values than the experimental group.

The maximum score that could be achieved on the high cognitive level questions of the first achievement test is 11. Students' scores on the high cognitive level questions of the first achievement test in the experimental group (mean=6.83) were higher than the control group (mean=5.85). However, the standard deviation in the high cognitive level questions of the first achievement test in the control group (2.26) was less than the experimental group (2.31) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group. On the other hand, the maximum score that could be achieved on the high cognitive level questions of the second achievement test is 13.5. Students' scores on the high cognitive level questions in the second achievement test in the experimental group (mean=7.48) were higher than the control group (mean=6.97). However, the standard deviation in the high level questions of the second achievement test in the control group (2.16) was less than the experimental group (2.29) indicating that students' scores in the control group were closer to the mean and spread over a narrower range of values than the experimental group.

Table 4.5. Means and Standard Deviations of the High Levels of Blooms Taxonomy in the Second Achievement Test on the Control and Experimental Group

Group	Application 2		Analysis 2		Synthesis 2		Evaluation 2	
	x̄	SD	x̄	SD	x̄	SD	x̄	SD
Control Group	1.57	0.74	3.27	1.36	1.20	0.55	0.93	0.54
Experimental Group	1.87	0.93	3.52	1.45	1.14	0.55	0.95	0.49

In order to answer the first question (What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' achievement?), two concept tests (one for each chapter)were used as pretests and posttests. A univariate analysis of covariance (ANCOVA) was conducted on the data from the two cellular biology concept tests with the pretest as a covariate and the post-test as the dependent variable in order to determine if significant differences existed between the scores of students in the experimental groups and the control groups. Results from this univariate ANCOVA for first and second concept tests appear in Tables 4.6 and 4.7 respectively. The results of the first concept test showed that students in the control group scored higher but not significantly higher than students in the experimental group ($p=0.704>0.05$). Moreover, students in the control group scored higher but not significantly than students in the experimental group ($p= 0.878>0.05$) in the second concept test.

Table 4.6. Univariate ANCOVA of First Concept Test for Post-test Scores of the Experimental and Control Groups with the Pre-test Scores as the Covariate

Source	Sum of Squares	df	Mean Square	F Ratio	Sig
Between Groups	1.163	1	1.163	0.146	0.704
Error	494.948	62	7.983		
Total	9777.000	65			
Corrected Total	584.246	64			

Table 4.7. Univariate ANCOVA of Second Concept Test for Post-test Scores of the Experimental and Control Groups with the Pre-test Scores as the Covariate

Source	Sum of Squares	df	Mean Square	F Ratio	Sig
Between Groups	0.643	1	0.643	0.024	0.878
Error	1674.676	62	27.011		
Total	22557.000	65			
Corrected Total	1962.400	64			

As indicated in Tables 4.2 and 4.3, in addition to the two concept tests that were conducted as a pre- and posttests, the students took two achievement tests (one after each chapter). An independent samples t-test was conducted for each of the two achievement tests. Results of the t-test for achievement test one and two are summarized in Table 4.8. Students' scores on the first achievement test were not significantly higher in the experimental group than the control group ($p=0.24>0.05$). Similarly, students' scores on the second achievement were not significantly higher in the experimental group than the control group ($p=0.92>0.05$).

Table 4.8. Results of the Independent Samples t-test for the First and Second Achievement Test of the Control and Experimental Group

	Group								
	Control			Experimental					
	$\bar{x}$	SD	N	$\bar{x}$	SD	N	t	df	p
Achievement 1	23.58	4.40	32	23.83	5.55	33	-0.21	63	0.24
Achievement 2	20.30	4.67	32	21.37	4.84	33	-0.91	63	0.92

In order to answer the second research question (What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' attitudes toward biology?), a biology attitude scale was used as pretest and posttest. A univariate analysis of covariance (ANCOVA) was conducted on the data from the pre-post biology attitude scale with the pretest as a covariate and the post-test as the dependent variable in order to determine if significant differences existed between the scores of students in the experimental groups and the control groups. Results from this univariate ANCOVA for the pre-post attitude scales appear in Table 4.9. The results of the attitude scale showed that students in the control group scored higher but not significantly higher than students in the experimental group (p=0.739>0.05).

Table 4.9. Univariate ANCOVA of Biology Attitude Scale for Post-test Scores of the Experimental and Control Groups with the Pre-test Scores as the Covariate

Source	Sum of Squares	df	Mean Square	F Ratio	Sig
Between Groups	17.851	1	17.851	0.112	0.739
Error	9693.032	61	158.902		
Total	557970.000	64			
Corrected Total	24339.750	63			

As indicated in Tables 4.4 and 4.5, the items of the two achievement tests were categorized into low and high cognitive level questions. The low cognitive levels category includes knowledge and comprehension question while the high cognitive level category includes application, analysis, synthesis and evaluation questions. An independent samples t-test was conducted for each of the two cognitive level categories in the two achievement tests. Results of the t-test scores for the low and high cognitive level questions of achievement test one and two are summarized in Table 4.10.

Concerning the scores of the two cognitive level categories , students' scores on the low cognitive level questions in the first achievement test were not significantly higher in the experimental group than the control group ($p=0.39>0.1$). In contrast, students' scores on the high cognitive level questions in the first achievement test were significantly higher in the experimental group than the control group ($p= 0.08<0.1$). Moreover, students' scores on the low cognitive level questions in the second achievement test were not significantly higher in the experimental group than the control group ($p=0.46>0.1$). Similarly, students' scores on the high cognitive level questions in the second achievement test were not significantly higher in the experimental group than the control group ($p= 0.36>0.1$).

Table 4.10. Results of the Independent Samples t-test for the Low and High cognitive level questions of the Two Achievement tests for the Control and Experimental Group

	Group								
	Control			**Experimental**					
	$\bar{x}$	**SD**	**N**	$\bar{x}$	**SD**	**N**	**t**	**df**	**p**
Low Bloom 1	17.73	2.80	32	17.00	3.88	33	0.863	63	0.39
High Bloom 1	5.85	2.26	32	6.83	2.31	33	-1.734	63	0.08
Low Bloom 2	13.33	3.10	32	13.89	2.97	33	-0.751	63	0.46
High Bloom 2	6.97	2.16	32	7.48	2.29	33	-0.921	63	0.36

*p<0.1

4.2. Supplementary Analysis: Two-Tier Concept Tests

In order to further understand the results of the study, the number of correct answers, reasons and both were computed for every two-tier concept test item (that tested for a specific cellular biology concept) before and after the intervention. The results of the first concept test are presented in Tables 4.11 and 4.12 for the control and experimental group respectively. In addition, the results of the second concept test are presented in Tables 4.13 and 4.14 for the control and experimental group respectively.

The total number of students in this study was 65 with 32 students in the control group and 33 in the experimental group. Analyzing the student scores for each test item of the first concept test showed that students' correct answers were relatively low at the beginning of the study in the following concepts: Definition of a cell (14 correct answers in the experimental group), prokaryotic cell (7 correct answers in the experimental group and 10 correct answers in the control group). In both groups, the number of students' correct answers improved in all items of the post-test except for the definition of a cell in the control group (24 correct answers in the pre-test vs. 19 correct answers in the post-test) and the building blocks of cells in the control group (28 correct answers in the pre-test vs. 26 correct answers in the post-test). In addition, students' correct answers of the control group improved on the following items: prokaryotic cell (27 correct answers), function of the nucleus (31 correct answers), and plant vs. animal cells (32 correct answers). However, unlike the control group, students' correct answers of the experimental group improved on all of the following items: definition of a cell (18 correct answers), building blocks of cells (31 correct answers), prokaryotic cell (25 correct answers), function of the nucleus (33 correct answers) and plant vs. animal cells (31 correct answers).

Analyzing the student scores for each test item of the first concept test showed that students' correct answers were relatively low at the beginning of the study in the following concepts: Definition of a cell (14 correct answers in the experimental group), prokaryotic cell (7 correct answers in the experimental group and 10 correct answers in the control group).In both groups, the number of students' correct answers improved in all items of the post-test except for the definition of a cell in the control group (24 correct answers in the pre-test vs. 19 correct answers in the post-test) and the building blocks of cells in the control group (28 correct answers in the pre-test vs. 26 correct answers in the post-test). In addition, students' correct answers of the control group improved on the following items: prokaryotic cell (27 correct answers), function of the nucleus (31 correct answers), and plant vs. animal cells (32 correct answers). However, unlike the control group, students' correct answers of the experimental group improved on all of the following items: definition of a cell (18 correct answers), building blocks of cells (31 correct answers), prokaryotic cell (25 correct answers), function of the nucleus (33 correct answers) and plant vs. animal cells (31 correct answers). Moreover, students in the experimental group scored higher than the control group on the following items in the post-test: building blocks of cells (31 correct answers) and function of the nucleus (33 correct answers).

Analyzing the student scores for each test item of the first concept test showed that students' correct reasons were low at the beginning of the study in the following concepts: prokaryotic cell (15 correct reasons in the control and 10 correct reasons in the experimental) and function of the nucleus (13 correct reasons in the control and 12 correct reasons in the experimental).In both groups, the number of students' correct reasons improved in all items of the post-test except definition of a cell in the experimental group (28 correct reasons in the pre-test vs. 26 correct reasons in the post-test).In addition, students' correct reasons of the experimental group improved on the following items: building blocks of cells (28 correct reasons), prokaryotic cell (27 correct reasons), function of the nucleus (27 correct reasons) and plant vs. animal (33 correct reasons).However, unlike the experimental group, students' correct reasons of the control group improved on all of the following items: definition of a cell (29 correct reasons), building blocks of cells (25 correct reasons), prokaryotic cell (30 correct reasons), function of the nucleus (23 correct reasons) and plant vs. animal cells (32 correct reasons).Moreover, students in the experimental group scored higher than the control group on the following item in the post-test: Function of the nucleus (27 correct reasons) and building blocks of cells (28 correct reasons).

Analyzing the student scores for each test item of the first concept test showed that the alignment of students' correct answers with correct reasons was low at the beginning of the study in the following concepts: prokaryotic cell (6 in the experimental group and 9 correct in the control group) and function of the nucleus (11 in the experimental and 11 in the control group).In both groups, the number of students' correct answers aligned with the correct reasons improved in all items of the post-test except for the definition of a cell in the control group (22 in the pre-test vs. 17 in the post-test).In addition, students' correct answers and reasons of the control group improved on the following items: building blocks of cells (25 correct answers and reasons), prokaryotic cell (26 correct answers and reasons), function of the nucleus (23 correct answers and reasons) and plant vs. animal cells (32correct answers and reasons).However, unlike the control group, students' correct answers and reasons of the experimental group improved on all of the following items: definition of a cell (18 correct answers and reasons), building blocks of cells (27 correct answers and reasons), prokaryotic cell (25 correct answers and reasons), function of the nucleus (27 correct answers and reasons) and plant vs. animal cells (31 correct answers and reasons).Moreover, students in the experimental group scored higher on the following item in the post-test: building blocks of cells (27 correct answers and reasons) and function of the nucleus (27 correct answers and reasons).

Table 4.11. Number of Correct Responses on Pre and Post-Test Items of the First Concept Test of Control Group

	Pre-test			Post-test		
Concept	**Answer**	**Reason**	**Both**	**Answer**	**Reason**	**Both**
Definition of a cell	24	27	22	19	29	17
Building Blocks of cells	28	23	21	26	25	25
Prokaryotic cell	10	15	9	27	30	26
Function of the nucleus	23	13	11	31	23	23
Plant vs. Animal cells	22	24	21	32	32	32

Table 4.12. Number of Correct Responses on Pre and Post-Test Items of the First Concept Test of Experimental Group

	Pre-test			Post-test		
Concept	**Answer**	**Reason**	**Both**	**Answer**	**Reason**	**Both**
Definition of a cell	14	28	13	18	26	18
Building Blocks of cells	28	23	23	31	28	27
Prokaryotic cell	7	10	6	25	27	25
Function of the nucleus	28	12	11	33	27	27
Plant vs. Animal cells	23	25	21	31	33	31

Analyzing the scores for each test item of the second concept test showed that students' correct answers were relatively low at the beginning of the study in the following concepts: Concentration gradient vs. diffusion rate (12 in the experimental group and 11 in the control group), concentration (18 in the experimental and 16 in the control group), equilibrium (14 in both the control and experimental groups), process of osmosis (8 in the control and 7 in the experimental group),effect of hypertonic solution on cells (12 in the control and 15 in the experimental group), osmosis as passive transport (7 in the control group and 3 in the experimental group), and semi-permeable membrane (9 in the control and 11 in the experimental group).In both groups, the number of students' correct answers improved in all items of the post-test except for the example of diffusion in the control group (25 correct answers in the pre-test vs. 21 correct answers in the post-test) and the concentration gradient vs. diffusion rate in the control group (11 correct answers in the pre-test vs. 11 correct answers in the post-test).In addition, students' correct answers of the control group improved on the following items: process of diffusion (29 correct answers), concentration (27 correct answers), equilibrium, (25 correct answers), temperature vs. diffusion rate (24 correct answers), process of osmosis (27 correct answers), effect of hypertonic solution on cells (23 correct answers), osmosis as passive transport (16 correct answers) and semi-permeable membrane (25 correct answers).

However, unlike the control group, students' correct answers of the experimental group improved on all of the following items: Example of diffusion (22 correct answers), process of diffusion (32 correct answers),concentration gradient vs. diffusion rate (22 correct answers) concentration (22 correct answers), equilibrium, (17 correct answers), temperature vs. diffusion rate (28 correct answers), process of osmosis (24 correct answers), effect of hypertonic solution on cells (26 correct answers) , osmosis as passive transport (17 correct answers) and semi-permeable membrane (30 correct answers).Moreover, students in the experimental group scored higher than the control group on the following items in the post-test: example of diffusion (22 correct answers), process of diffusion (32 correct answers), concentration gradient vs. diffusion rate (22 correct answers), temperature vs. diffusion rate

(28 correct answers), effect of hypertonic solution on cells (26 correct answers), osmosis as passive transport (17 correct answers) and semi-permeable membrane (30 correct answers).

Analyzing the scores for each test item of the second concept test showed that students' correct reasons were low at the beginning of the study in the following concepts: Example of diffusion (11 in the control and 6 in the experimental group) ,Concentration gradient vs. diffusion rate (2 in the experimental group and 6 in the control group), concentration (13 in the experimental and 8 in the control group), equilibrium (12 in the control and 9 in the experimental group), process of osmosis (8 in the control and 7 in the experimental group), effect of hypertonic solution on cells (7 in the control and 1 in the experimental group), osmosis as passive transport (6 in the control and 4 in the experimental group), and semi-permeable membrane (10 in the control and 8 in the experimental group).In both groups, the number of students' correct reasons improved in all items of the post-test except for the process of diffusion in the experimental group (12 correct reasons in the pre-test vs. 11 correct reasons in the post-test) and the concentration gradient vs. diffusion rate in the control group (6 correct reasons in the pre-test vs. 5 correct reasons in the post-test) .In addition, students' correct reasons of the experimental group improved on the following items: Example of diffusion (20 correct reasons), concentration gradient vs. diffusion rate (7 correct reasons), concentration (24 correct reasons), equilibrium (15 correct reasons), temperature vs. diffusion rate (27 correct answers), process of osmosis (22 correct reasons), effect of hypertonic solution on cells (8 correct reasons), osmosis as passive transport (17 correct reasons), and semi permeable membrane (31 correct reasons).

However, unlike the experimental group, students' correct reasons of the control group improved on all of the following items: example of diffusion (16 correct reasons), process of diffusion (19 correct reasons), concentration (19 correct reasons), equilibrium (23 correct reasons), temperature vs. diffusion rate(25 correct reasons), process of osmosis (19 correct reasons), effect of hypertonic solution on cells (10 correct reasons), osmosis as passive transport (14 correct reasons), and semi permeable (24 correct reasons).Moreover, students in the experimental group scored higher than the control group on the following item in the post-test: Example of diffusion (20 correct reasons), concentration gradient vs. diffusion rate (7 correct reasons), concentration (24 correct reasons), temperature vs. diffusion rate (27 correct reasons), process of osmosis (22 correct reasons), osmosis as passive transport (17 correct reasons), and semi-permeable membrane (31 correct reasons).

Analyzing the student scores for each test item of the second concept test showed that the alignment of students' correct answers with correct reasons was low at the beginning of the study in the following concepts: example of diffusion (5 in the experimental group and 8 in the control group), concentration gradient vs. diffusion rate (1 in the experimental group and 6 in the control group), concentration (12 in the experimental and 8 in the control group) ,equilibrium (9 in the control group and 7 in the experimental group), process of osmosis (3 in the control group and 4 in the experimental group), effect of hypertonic solution on cells (4 in the control group and 1 in the experimental group), osmosis as passive transport (2 in the experimental group and 5 in the control group), and semi-permeable membrane (7 in the experimental group and 4 in the control group). In both groups, the number of students' correct answers aligned with the correct reasons improved in all items of the post-test except for the process of diffusion in the experimental group (11 in the pre-test vs. 11 in the post-test) and concentration gradient vs. diffusion rate in the control group (6 in pre-test vs. 4 in the post-test). In addition, students' correct answers and reasons of the control group improved on the following items: example of diffusion (15 correct answers and reasons), process of diffusion (19 correct answers and reasons), concentration (18 correct answers and reasons) , equilibrium (22 correct answers and reasons), temperature vs. diffusion rate (24 correct answers and reasons), process of osmosis (19 correct answers and reasons), effect of hypertonic solution on cells (9 correct answers and reasons), osmosis as passive transport (13 correct answers and reasons), and semi-permeable membrane (19 correct answers and reasons).

However, unlike the control group, students' correct answers and reasons of the experimental group improved on all of the following items: example of diffusion (16 correct answers and reasons), concentration gradient vs. diffusion rate (6 correct answers and reasons), concentration(21 correct answers and reasons), equilibrium (12 correct answers and reasons), temperature vs. diffusion rate (27 correct answers and reasons), process of osmosis (22 correct answers and reasons), effect of hypertonic solution on cells (8 correct answers and reasons), osmosis as passive transport (16 correct answers and reasons), and semi-permeable membrane (28 correct answers and reasons).Moreover, students in the experimental group scored higher on the following item in the post-test: example of diffusion (16 correct answers and reasons) , concentration gradient vs. diffusion rate (6 correct answers and reasons), concentration (21 correct answers and reasons),temperature vs. diffusion rate (27 correct answers and reasons), process of osmosis (22 correct answers and reasons), osmosis as passive transport (16 correct answers and reasons), and semi-permeable membrane (28 correct answers and reasons).

Table 4.13. Number of Correct Responses on Pre and Post-Test Items of the Second Concept Test of Control Group

	Pre-test			Post-test		
Concept	**Answer**	**Reason**	**Both**	**Answer**	**Reason**	**Both**
Example of Diffusion	25	11	8	21	16	15
Process of Diffusion	27	15	14	29	19	19
Concentration gradient vs. Diffusion rate	11	6	6	11	5	4
Concentration	16	8	8	27	19	18
Equilibrium	14	12	9	25	23	22
Temperature vs. Diffusion rate	23	23	18	24	25	24
Process of Osmosis	8	8	3	27	19	19
Effect of hypertonic solutions on cells	12	7	4	23	10	9
Osmosis as passive transport	7	6	5	16	14	13
Semi-permeable membrane	9	10	4	25	24	19

Table 4.14. Number of Correct Responses on Pre and Post-Test Items of the Second Concept Test of Experimental Group

	Pre-test			Post-test		
Concept	**Answer**	**Reason**	**Both**	**Answer**	**Reason**	**Both**
Example of Diffusion	20	6	5	22	20	16
Process of Diffusion	24	12	11	32	11	11
Concentration gradient vs. Diffusion rate	12	2	1	22	7	6
Concentration	18	13	12	22	24	21
Equilibrium	14	9	7	17	15	12
Temperature vs. Diffusion rate	23	24	23	28	27	27
Process of Osmosis	7	7	4	24	22	22
Effect of hypertonic solutions on cells	15	1	1	26	8	8
Osmosis as passive transport	3	4	2	17	17	16
Semi-permeable membrane	11	8	7	30	31	28

4.3. Qualitative Data Analysis

In an attempt to understand the level of students' engineering design skills about topics related to cellular transport, students in the control and experimental group were required to complete an engineering design task assessment at the end of the study. Unlike the control group, the experimental group was exposed to the science and engineering design practices and involved in lab activities that helped them build their engineering design skills. The engineering design topics included in the assessment were the following: assessment of osmosis setup, effect of osmosis on water level, factors affecting membrane permeability, functionality of diffusion design setup, and explanation of design testing.

4.3.1. Qualitative Analysis of the Levels of Engineering Design Skills

Students' written responses to the engineering design items were analyzed to measure the levels of proficiency of design skills. The items included different elements of engineering and design related to the content of cellular biology. In the first question (question 1a and 1b), students were asked to assess the cellular transport process demonstrated by a given setup and provide a justification for their choice. In addition, they were asked to assess the change in the water level as a result of osmosis. Other questions in the assessment required students to design a functional setup that demonstrates diffusion and explain how the design can be tested (e.g. questions 2 and 3). Table 4.15 presents the results of the evaluation of students 'responses. Students' responses for each of the engineering design elements were evaluated by using a rubric developed according to the engineering design elements of NGSS. According to this rubric, students' responses on engineering design questions are classified as proficient (level 3) , developing (level 2), beginner (level 1), and novice (level 0).A response was categorized as proficient (level 3) in question 1a and 1b when the participant gave a correct scientific answer supported by a correct scientific justification. In addition, a response was categorized as proficient (level 3) in question 1c when the student correctly stated the name of the molecule by considering the factors that have the potential to influence membrane permeability(e.g. particle size and concentration gradient).On the other hand, a response was categorized as proficient (level 3) in question 2 when the drawn design correctly tested the membrane permeability for the two tested substances and took into consideration the stated constraints. Moreover, a response was categorized as proficient (level 3) in question 3 when it explained the membrane permeability based on two substance-indicator reactions and by providing justifications that are aligned with the design.

A response was categorized as developing (level 2) in question 1a when the student stated the correct scientific term demonstrated by the given setup without providing a clear justification. However, a response was categorized as developing (level 2) in question 1b when the student provided a correct scientific justification related to concentration gradient without providing a correct answer. Moreover, a response was categorized as developing (level 2) in question 1c when the student gave the names of the molecules without taking into consideration the concentration gradient as a factor that affects membrane permeability. A response was categorized as developing (level 2) in question 2 when the drawn design tested the membrane permeability for the two tested substances without taking into consideration the stated constraints. Finally, a response was categorized as developing (level 2) in question 3 when it explains the membrane permeability based on two-substance indicator reactions without providing a justification aligned with the drawn design.

A response was categorized as beginner (level 1) in question 1a when the student stated the correct scientific term demonstrated by the given setup without providing a correct justification. Similarly, a response was categorized as beginner (level 1) in question 1b when the student provided a correct answer without providing a correct justification. Moreover, a response was categorized as beginner (level 1) in question 1c when the student stated the names of the molecules without taking into consideration the concentration gradient or the particle size as factors that affect membrane permeability. On the other hand, a response was categorized as beginner (level 1) in question 2 when the drawn design tested the membrane permeability for the one tested substance. In addition, a response was categorized as beginner (level 1) in question 3 it explained the membrane permeability based on one substance-indicator reaction without providing a justification aligned with the design.

A response was categorized as novice (level 0) in question 1a when the student did not provide a correct answer and a correct justification or both are missing. Similarly, a response was categorized as novice (level 0) in question 1b when the student did not provide a correct answer and justification or both are missing. A response was categorized as novice (level 0) in question 2 when the drawn design did not test the membrane permeability for any of the tested substances while a response was categorized as novice (level 0) in question 3 when it did not provide any relevant justification related to substance-indicator reactions and did not provide a justification aligned with the design. Results of students' level of engineering design skills are presented in Table 4.15.

Table 4.15. Number of Students at each Level of Engineering Design Skills in the Control and Experimental Groups

	Level	Assessment of Design			Functionality of Design	Explanation of Design Testing
		Question 1a	Question 1b	Question 1c	Question 2	Question 3
Control	3	11	17	3	5	4
	2	7	3	0	9	3
	1	5	3	6	4	5
	0	9	9	14	14	20
Experimental	3	23	20	6	9	3
	2	2	4	5	13	1
	1	5	0	7	1	7
	0	3	9	4	10	22

Results showed that the majority of students in both groups were at level 3 (proficient) in the questions related to the assessment of design (questions 1a and 1b). However, the number of students at level 3 (proficient) in the experimental group in questions 1a and 1b respectively was higher than the control group. For example, the number of students at level 3 (proficient) in questions 1a and 1b in the experimental group was 23 and 20 respectively. In contrast, the number of students at level 3 (proficient) in the same questions in the control group was 11 and 17 respectively. In addition, the number of students at level 0 (novice) in the experimental group (3 students) is lower than the number of students in the control group (9 students). Concerning the level of students' engineering design skills in question 1c, the number of students at level 3 (proficient) in the experimental group (6 students) was higher than the control group (3 students). On the other hand, the number of students at level 0 (novice) in the control group (14 students) was higher than the experimental group (4 students).

Concerning the level of students' engineering design skills in the question related to functionality of design (question 2), the number of students at level 3 (proficient) in the experimental group (9 students) is higher than the control group (5 students). Similarly, the number of students at level 2 (developing) in the experimental group (13 students) is higher than the control group (9 students). In contrast, the number of students at level 0 (novice) in the control group (14 students) is higher than the experimental group (10 students). Concerning the level of students' engineering design skills in the question related to explanation of design testing (question 3), the number of students at level 3 (proficient) is the control group (4 students) is relatively close to that of the experimental group (3 students). In addition, the number of students at level 0 (novice) in the experimental group (22 students) is slightly higher than the control group (20 students). Moreover, the number of students at level 2 (developing) in the control group (3 students) is slightly higher than the experimental group (1 student). In summary, students in the experimental group demonstrated higher skills in Assessment of design and explaining the functionality of design.

4.3.2. Reliability

To ensure the reliability of the results of the level of proficiency of engineering design skills, one researcher and two graduate students (who are also Biology teachers) met to discuss students' responses. Reliability was reached through inter-rater agreement by meeting to discuss the rubric for analyzing the level of students' engineering design skills. The researchers applied the rubric for analysis to one of the engineering design assessments to ensure that they shared an understanding of its different elements. Differences in the results were discussed until consensus was reached. Then, in the second step, the two graduate students separately analyzed some of the responses (for about 10 students) and the results were compared. They met again with one of the researchers to discuss the results and reach a consensus regarding the differences. Again the graduate students independently analyzed all other responses. The results were then compared and 90 % of the analysis was similar (inter-rater reliability was α=0.9). Finally, the researcher conducting this study pursued the analysis by herself.

4.3.3. Students' Interviews

In an attempt to answer the second research question (What are the effects of implementing scientific and engineering practices as compared to structured inquiry on eighth grade students' attitudes toward biology?), 23 students from the structured inquiry group and 26 students from the science and engineering design practices group answered ten questions in a semi-structured interview conducted after the completion of the study. These questions aimed to collect data about students' opinions regarding the use of the different instructional approaches used in biology. Results of the analysis of the students' responses to the questions are reported below.

When the students in the structured inquiry group were asked about the component of the instructional approach that they found very helpful to learn biology in general, 18 out of 23 students said that the guidelines provided in the procedure of the guided activities were helpful. The following excerpts illustrate what two students said:

Student SM 2C: Oh, I found helpful of how you used details in the procedure of what to do so it wasn't as hard.

Student SM 4C: The part that I found helpful is the instructions that you can read them properly and understand how to do the experiment

Four out of 23 students said that it was very helpful because it allowed them to see the actual results, something that they could not observe during the lesson in the classroom(such as diffusion of iodine through a semi-permeable membrane), and learn the concepts through hands-on activities. The following excerpts illustrate what three students said:

Student SM 1C: What I found helpful is that you could see what's happening in front of you and you could try it and you could see how it gets affected with the different substances we're using like for the potato we could see how it was different in salt solution and tap water.

Student SM 20C: *The most thing I found helpful is when you guys didn't always give us the answers you give us a try like we could do the things on our own and like to learn it by ourselves before asking questions before giving us all the answers. I found it better that you didn't give us the answers and try to do it ourselves before.*

Student SF 21C: What was helpful is that we were given the material and we tested it alone which helped us depend on ourselves at first.

However, 1 out of the 23 students said that the research he did for presenting their results helped him understand the lesson more than the laboratory activities. The following excerpt illustrates what students said:

Student SM 12C: The research, in some of our slides we had to put what is osmosis because sometimes I want to be too familiar because biology is hard so when I research stuff about osmosis and everything so I remember it better.

However, when students were asked about the components that were not helpful, 8 out of 23 students said that there was nothing unhelpful about the instructional approach. The following excerpts illustrate what two students said:

Student SF 5C: I didn't find anything to be unhelpful; I thought it was a good process I learned from it.

Student SF 6C: Nothing, because it all made us understand using the interactive activity.

Six students out of 23 said that the instructions were detailed and explicit and thus they did not have the chance to be creative. The following excerpts illustrate what students said:

Student SM14C: The main thing that was not helpful is that it wasn't that creative so instead of discovering diffusion or osmosis in our own way we were guided and I think that if we were able to do it in our own way with less guidance we might understand it more.

Student SM 19C: The materials aren't that helpful because you already gave them to us and they already told us the procedure.

In addition, 3 out of 23 said that they gained shallow knowledge and said that the approach was very straightforward and did not allow them to gain in-depth understanding of the content. The following excerpts illustrate what two students said:

Student SF 3C: There are also more things that you can learn once you make up your own experiment where you can understand extra parts , you could understand more about the semi-permeable membrane that you have to use and go deeper.

Student SM 15C: It didn't really teach you something because we learned osmosis then we just saw the experiment the same thing that he told us so we didn't learn anything.

Moreover, 4 out of 23 said that they were just applying the steps of the procedure given without having a clear understanding of the rationale of every step in the procedure and the generated results. The following excerpts illustrate what three students said:

Student SM12C: I don't but we were doing things without our understanding where we had to submerge the potato in water and salty water, I didn't really know what for and that was especially not helpful.

Student SF17C: The problem is that because we didn't know what the results will be and some of us got different results so we didn't know if we were right or wrong.

Student SM16C: We did not understand the results properly and we could not like explain the results.

Finally, 2 out of 23 said that this approach did not differentiate between students' cognitive abilities because all students have to learn in the same way. The following excerpts illustrate what two students said:

Student SF13C: It's just that if everything is given to you, you don't really learn based on you like sometimes if they give you visual reports, people who learn visually do better at memorizing it and understanding it.

Student SF 9C: Because everybody was doing the same thing you cannot improve your skills or can't improve anything.

To summarize, the majority of students in the structured-inquiry group found that the guidelines of the procedure provided were helpful with few students stating visual learning and hand-on activities as the helpful components. However, only one student claimed that the research performed during presentations as the helpful component.

Moreover, the majority of students said that there was nothing unhelpful in the activities. However, several students highlighted the lack of creativity due to explicit instructions as the unhelpful component. In addition, few students claimed that the "shallow" knowledge generated from this approach did not leave a room for in-depth understanding of content. Several students also indicated that they applied the steps of the procedure without a clear understanding of the rationale of every step or the generated results. A minority of students also mentioned that this approach does not differentiate between the cognitive abilities of students.

When the students were asked whether the structured inquiry approach helped them gain a better understanding of the biology concepts than their learning in the biology classroom, 8 out of 23 students said that it helped them without specifying reasons. The following excerpts illustrate what two students said:

Student SF23C: Yeah, it helped me understand the biology content more than lectures in class.

Student SF22C: They help me understand more about diffusion and osmosis.

Four students also said that the structured inquiry approach helped them due to visual learning and hand-on activities:

Student SM1C: Yeah a lot because I like learning but learn better when I see it in front of me and this gave me the chance.

Student SF13C: The experiment was better because when we saw them and everything it was good for us to like see it because we knew exactly how it looked like and everything.

Furthermore, 3 out of 23 said that the structured inquiry approach “kind of helped them” gain a better understanding but not that much as illustrated in the following excerpts

Student SF5C: Yes, kind of it just helps.

Student SF10C: yeah kind of but the thing is that it makes everybody understand it in exactly same way but we don’t all learn from it.

In addition, 4 out of 23 said that it did not help them due to the lack of research and creativity as illustrated in the excerpts below:

Student SF11C: Not really because we really had all the stuff, if we researched it will stick into our minds and we will be the people finding the information rather than having it given to us.

Student SM19C: No, it didn't because I didn't think of biology reasons I just thought of the experiment

However, 2 out of 23 said that they prefer the unguided/unstructured inquiry activities rather than the structured inquiry approach because it encourages creativity and produces better understanding:

Student SM3C: yeah but I think that the open activities like engineering design would have helped me more understand the topic.

Student SM8C: I learn both ways but I like to use my creativity more.

Finally, 2 out of 23 students said that the performed presentations in class helped them gain a better understanding. The following excerpt illustrates what one student said:

Student SM12C: Yeah, it helped us perform better because the material in our presentations was included in our tests so I just remembered it.

When students were asked whether they recognized the different components of laboratory activities and the classroom teaching, 16 students recognized a clear link between the structured-inquiry lab activities and the explanation in the biology classroom. The following excerpts illustrate this idea:

Student SM1C: There was a link because we learned osmosis in class and we could do it. The same goes for diffusion like we learned the concept and we saw it.

Student SF1C: I feel that the link was strong because it was the same thing as the information we were given in the videos.

However, 6 students said that the link between the structured-inquiry lab activities and the explanation in the biology classroom was unclear as can be seen in the following excerpts:

Student SM20C: The link was not that much because like when he was explaining in class, I found it was kind of different from the experiment.

Student SF13C: There was a sort of a link like we were doing the things that he taught us about and he said something about something we would do. The link was clear in some parts because they gave us good instructions.

Finally, 1 out of 23 students did not recognize any link. The following excerpt illustrates what this student said:

Student SM19C: No, because Mr. Barakat teacher teaches us things that we don't like see them happen. He showed us videos about cells and we cannot see them happen.

To summarize, the majority of students said that the structured-inquiry approach helped them gain a better understanding of the biology concepts than their learning in the biology classroom. However, few students said that it helped them to some extent. Moreover, several students indicated that it did not help them due to lack of creativity, with few students preferring unguided activities over guided activities. A minority of students indicated that the presentations performed in class rather than the activities themselves as the component that promoted conceptual understanding of biology. In addition, the majority of students recognized a clear link between the lab activities and the classroom explanation.

When students were asked whether they would like to use structured inquiry once again in other biology units, 11 out of 23 students replied that they would like to use structured-inquiry in other biology units as illustrated in the excerpts below:

Student SM2C: I prefer these structured activities because open activities can be a chaos at some time.

Student SM7C: Yes, I prefer those activities over other activities.

However, 9 students said that they preferred unguided (unstructured) inquiry activities. The following excerpts illustrate this position:

Student SF10C: The other way is better for the long-term because in that way you have experience creating stuff from your own instead of following directions.

Student SF13C: I wouldn't because I am more of a person who likes to do visual and creative work. Like personally, I prefer building and researching it helps me more.

Finally, 3 out of 23 students suggested that the use of unguided activities work better for experts while structured-inquiry works better for novices. The following excerpts illustrate what two students said:

Student SF11C: I would suggest using both approaches, first introduce the topic using structured inquiry activities and later we could like do it alone.

Student SM1C: I prefer using open activities as long as I know the concepts.

Concerning gaining knowledge and skills from using the guided inquiry approach, 15 students said that they gained only knowledge while 8 students said that they gained both knowledge and skills. The following excerpts illustrate what two students said:

StudentSF17C: It improved in my knowledge more.

Student SM7C: Both, like in terms of skills I learned a lot for example I learned how to measure masses.

When students were asked if they enjoyed the activities, 21 out of 23 students said that they enjoyed the structured-inquiry activities as illustrated in the following excerpts.

Student SM1C: It was much better than just taking notes, it was nicer to do the activities and learn from them.

Student SM2C: yes because it made learning more fun than just studying.

However, 2 out of 23 students said that they did not enjoy them. The following excerpts illustrate what they said:

Student SF10C: Not really, I found them very boring I had to read the entire script and follow every single direction.

Student SM18C: I did not enjoy them that much but I did fine.

To summarize, the majority of students preferred using structured inquiry activities. However, a number of students preferred using unguided inquiry over guided inquiry. In contrast, few students suggested that using guided inquiry works better for novices while unguided inquiry works better for experts. Moreover, the majority of students claimed that they just gained knowledge with several students claiming that they only gained skills. In addition, most students indicated that they enjoyed the structured inquiry activities.

When students were asked whether the activities were hard or not, 9 out of 23 students said that the structured-inquiry approach was not hard at all because of the guidelines provided in the procedure while 10 students said it was not hard without specifying the reasons. The following excerpts illustrate what the students said:

Student SM14C: I think that the structured inquiry is easy because you have everything given to you.

Student SM 4C: No because they are guided well.

Moreover, 1 out of 23 students said that the structured inquiry approach was not hard to use but students need to pay careful attention to the steps provided in the procedure:

Student SM7C: It's not hard but you need to pay attention to the steps given.

However, 1 out of 23 students said the approach becomes only difficult when you get unexpected results:

Student SF9C: It depends because if you are supposed to expect something and it didn't happen within the time it is supposed to happen, problem happens.

Finally, 2 out of 23 students found the activities hard and confusing as illustrated in the excerpts below:

Student SM16: I think yeah a bit hard because sometimes you get confused between these things and you connect them differently.

Student SF13C: The straightforward activities are hard for me because I'm more of a person who doesn't really like to memorize.

When students were asked whether they would like to use the structured-inquiry approach in other science courses, 15 out of 23 said that they would like to use the structured-inquiry approach in other science courses. The following excerpts illustrate this position:

Student SM14C: I think it should be used a lot more in chemistry because you have to take element and stuff and facts are taught and when you need to learn facts , the structured activities are better.

Student SM 2C: yeah it's nice because it helps you understand more and you would like visualize it.

However, 4 students said that they would not like to use it and preferred using unguided inquiry activities in science courses other than biology as illustrated in the following excerpt:.

Student SM8C: No, I prefer the open activities.

Student SM 14C: If I had the option to choose I would definitely to the approach that is more free.

Moreover, 2 students suggested that the use of unguided activities in all science works better for experts while structured-inquiry works better for novices as illustrated in the excerpts below:

Student SM4C: As I said before I prefer to start with the guided activities and then step by step getting harder and harder.

Student SM14C: For those people who don't understand me well I show them two or three videos for students to understand more.

Finally, 3 students said that they were not sure if they would like to use the structured-inquiry approach in other science courses as illustrated in the excerpts below:

Student SF9C: Not sure, it depends on the subject.

Student SM15C: I don't know and I'm not sure.

When students were asked about the changes that they would like to make in order to improve the use of the structured inquiry activities, 13 out of 23 students suggested that the activities need to be modified to leave a room for students' freedom and creativity as illustrated in the excerpts below:

Student SM1C: I will change it so it's not so guided so we can do our own thing in it and maybe try it in different situations for example: in a cooler or hotter place so that we can learn more about how it's affected.

Student SF17C: I won't exactly make it that easy I won't like give all the steps.

Seven students out of 23 suggested that nothing needs to be changed and that the activities are good as presented. The following excerpts illustrate this point:

Student SF5C: Like they were good and I will not change anything.

Student SM20C: Nothing, the experiments were the best

Finally, 2 students out of 23 suggested that they are not sure what to improve:

StudentSM7C: I'm not sure I would change anything because I like the way it was and got students participate in it.

Student SM 15C: I don't know.

To summarize, the majority of students found the approach easy. However, few students found it difficult with one student finding it difficult when unexpected results are generated. In addition, most students indicated that they would like to use the structured-inquiry approach in other science courses. However, several students preferred using the unguided inquiry. A few students indicated that they were not sure whether they would implement guided inquiry in other science courses with one student suggesting the use of guided-inquiry for novices versus unguided-inquiry for experts. Finally, most students suggested leaving a room for students' freedom and creativity. Several students indicated that there is nothing to be changed in the structured-inquiry activities while only one student suggested using more guided activities for novices.

When the students in the science and engineering practices group were asked about the component of the instructional approach that they found very helpful to learn biology in general, 18 out of 26 students said that it was helpful because it allowed them to learn the concepts through hands-on and opened a room for creativity. The following excerpts illustrate what students said:

Student SF1E: The hands-on approach I guess. The idea that we actually went through it even though it was hard to find the experiment, we found it and we did it ourselves and we could find it work and we could see it different than other things.

Student SF2E: The main part I think is when we had to create and saw how it failed and then we could correct it and do the right thing the next time because in our experiments they told us what to do and didn't tell us why it didn't work.

4 out of 26 students said that it was helpful because of the research component. The following excerpts illustrate what two students said:

Student SF3E: It was helpful because I honestly did not understand what osmosis was until I did the experiment and I was able to research.

Student SM9E: *Researching using the internet*

Finally, 1 out of 26 suggested that gaining skills was the helpful component as illustrated below:

Student SF7E: we focused a lot more on not just conceptual understanding we also focused more on skills that we could use outside the classroom.

However, 3 out of the 26 students said it has helpful because it allowed them to work with their partners. The following excerpt illustrates what one student said:

Student SF5E: Collaborative learning.

Student SF15E: I liked that we were in groups because it helps get different ideas, different sense of learning and different levels.

However, when students were asked about the components that were not helpful, 8 out of 26 students said that the guidelines for the implementation of the engineering design process were not clear. The following excerpts illustrate what two students said:

Student SF7E: Just make the guidelines slightly less blurry because it took a while to understand what we are supposed to do.

Student SM11E: Many students have failed because they didn't have guidelines or rubric to follow.

However, 4 out of 26 said that their content knowledge was insufficient to implement the engineering design activities and hence impeded their progress in the activities. The following excerpts illustrate what students said:

Student SF13E: Probably, the teacher could have explained even more.

Student SF15E: It was hard not to have enough basic knowledge because it requires more basic knowledge to understand it.

5 students out of 26 said that there was nothing unhelpful about the instructional approach as illustrated below:

Student SM19E: I think nothing.

Student SF5E: Nothing.

In addition, 7 out of 26 said that the constraints provided were not helpful because they were restricted by the list of materials provided. The following excerpts illustrate what two students said:

Student SM4E: The main part that we found not helpful was the materials restriction because there are things and materials that we found online that we could have used but because of the materials restriction we had to use others.

Student SF12E: I didn't feel very free like it's very limited in the kind of ideas that you can come up with. Like we weren't able to use the iodine with the corn starch.

However, only one student highlight the limited amount of time for the completion of the design projects as the unhelpful component. The following excerpt illustrates what the student said:

Student SF2E: A lot of us didn't have much time because we only had few blocks because we failed at the first time.

To summarize, the majority of students in the science and engineering practices group found that the hands-on activities and the room for creativity were helpful with several students stating research as the helpful component. However, one student claimed the gain of skills as the helpful component. Finally, a few students claimed collaborative learning as the helpful component.

Moreover, the majority of students highlighted the lack of clear guidelines of the engineering design process and the constraints provided were the unhelpful components. Moreover, several students said that there was nothing unhelpful in the activities. In addition, a few students claimed that the lack of sufficient amount of content knowledge impeded their progress in the activities. However, one student only mentioned the limited amount of time as the unhelpful component.

When the students were asked whether the science and engineering practices approach helped them gain a better understanding of the biology concepts than their learning in the biology classroom, 24 out of 26 students said that it helped them. The following excerpts illustrate what two students said:

Student SF2E: Yes, it helped me more with the explanation because now you can see it how it happened.

Student SF13E: Yeah, I definitely like learned it better and understood because of like how we could experiment the things.

However, 2 out of 26 said that it did not help them as illustrated in the excerpts below:

Student SF12E: No, I feel that I have the same amount of knowledge that I had in biology.

Student SF22E: I mean commonly the traditional way is somewhat simpler because the information is given to the students. Well, I think learning is very difficult in science overall.

When students were asked whether they recognized the different components of laboratory activities and the classroom teaching, 23 students recognized a clear link between the science and engineering practices lab activities and the explanation in the biology classroom. The following excerpts illustrate this idea:

Student SF13E: Well, yeah the activities were based in a way on the things that we learned so they were definitely linked.

Student SM9E: I think there was a strong link because he would give us the definition and also have to relate to the observations of the experiment.

However, 2students said that the link between the science and engineering practices and the explanation in the biology classroom was unclear as can be seen in the following excerpts:

Student SF16E: The link was very small because what Mr. Barakat taught us by giving us notes which I found really helpful but there was a very limited link because he never gave us engineering design or the NGSS thing.

Student SF25E: Yeah, it wasn't that clear when we started the experiment because I had no idea how they do with each other.

Finally, 1 out of 23 students did not recognize any link. The following excerpt illustrates what this student said:

Student SF2E: There wasn't actually a link because what the teacher was explaining about was different from what we had to do.

To summarize, the majority of students said that the science and engineering practices approach helped them gain a better understanding of the biology concepts than their learning in the biology classroom. However, only two students said it did not help them. In addition, the majority of students recognized a clear link between the lab activities and the classroom explanation.

When students were asked whether they would like to use science and engineering practices once again in other biology units, 23 out of 26 students replied that they would like to use the science and engineering practices in other biology units as illustrated in the excerpts below:

Student SM6E: It's boring to have everything on a slide show so it's better that you actually do it because if you'll do it you'll memorize it better.

Student SM4E: I think I would because it's much better than like if we're doing a big project so I would rather do it this way.

However, 1 out of 26 said that she would only like to use it if clear guidelines are present. The following excerpts illustrate this position:

Student SF12E: No, try to specify your steps at the end of it. It's kind of weird because we usually do a lot of things at once.

In addition, 1 out of 26 suggested using it for selective topics in biology. The following excerpt illustrate what the student said:

Student SF16E: Yes, but not the whole biology but only few topics in order to understand it.

Finally, 1 out of 26 suggested that he wouldn't like to use it because it's confusing. The following excerpt illustrates what the student said:

Student SM23E: I think No because I really got lost some of the time.

Concerning gaining knowledge and skills from using the science and engineering practices approach, 20 students said that they gained both knowledge and skills:

Student SM6E: It's more with knowledge and a bit with skills.

Student SF5E: Both

While, 5 students said that they gained only skills:

Student SM23E: I think of skills more.

Student SF13E: It helps in skills and in away like experience.

However, one student said that she gained only knowledge:

Student SF3E: Yes, it helps me gain more knowledge.

When students were asked if they enjoyed the activities, 25 out of 26 students said that they enjoyed the science and engineering design activities as illustrated in the following excerpts.

Student SM4E: Yeah, it was very fun because there was a lot more to. It's much more fun and helped us learn more.

Student SM9E: yeah, I like biology.

However, 1 out of 26 students said that she did not enjoy them. The following excerpt illustrates what the student said:

Student SF12E: Not that much honestly I found them confusing.

To summarize, the majority of students preferred using the science and engineering practices activities. However, few students did not prefer using it. Moreover, the majority of students claimed that they gained both knowledge and skills with several students claiming that they only gained skills. In addition, most students indicated that they enjoyed the science and engineering practices activities.

When students were asked whether the activities were hard or not, 25 out of 26 students said that the science and engineering practices approach was challenging. The following excerpts illustrate what the students said:

Student SM11E: They were a bit challenging but I don't say it's hard.

Student SF13E: There were some difficulties but it's not necessarily that hard, like it was challenging.

However, 1 out of 26 students said that the science and engineering practices approach was only challenging when the student doesn't have the sufficient amount of content knowledge:

Student SF3E: No, it's easy but you need to know the material before you start.

When students were asked whether they would like to use the science and engineering practices approach in other science courses, 25 out of 26 said that they would like to use the science and engineering practices approach in other science courses. The following excerpts illustrate this position:

Student SF5E: Yeah, it taught me many things like to work well in my group, to put my full effort and to think deeply and sometimes outside the box.

Student SM18E: Yes, it applies to everything in science and helps us in all topics not just biology.

However, 1 student said that she is not sure whether she would like to use in other science courses as illustrated in the following excerpt:.

Student SF12E: It depends on what's the project ends up being.

When students were asked about the changes that they would like to make in order to improve the use of the science and engineering practices approach, 9 students out of 26 suggested the need for more time to better improve and implement their designs:

Student SM6E: Not sure, maybe more time to finish our projects.

Student SM4E: I think they should give us extra time for redo and maybe some guidance by the teacher.

Eight students out of 26 suggested that nothing needs to be changed and that the activities are good as presented. The following excerpts illustrate this point:

Student SF5E: I wouldn't change anything.

Student SF8E: I have no suggestions.

Four students out of 26 suggested the need for minimizing the constraints in the engineering design activities and more specifically the constraints related to the use of materials. The following excerpts illustrate what the students said:

Student SF2E: Like give more materials. We didn't know what to use from the materials, if we had more materials we would go and ask what works as a membrane and put it.

Student SM26E: I would like to avoid materials restriction.

In addition, 9 out of 26 suggested the need for teaching more in-depth content knowledge and more explicit guidelines to better implement their designs:

Student SF1E: I don't know just explaining things a bit clearer again; I didn't really understand the project at first and didn't understand what we had to do in the first class.

Student SF25E: Make sure that that we have a basic understanding because when we first the experiment I didn't understand anything. I suggest that from the beginning a deeper understanding of the knowledge.

Finally, 1 out of 26 suggested implementing the science and engineering designs more often as illustrated in the following excerpt:

Student SM19E: Probably, to make it more often.

To summarize, the majority of students found the approach challenging. However, only one student said that it is only challenging when the students lack the sufficient amount of content knowledge. In addition, most students indicated that they would like to use the science and engineering practices approach in other science courses. Most students also suggested need for more explicit guidelines and sufficient amount of content knowledge in order to better use the science and engineering practices approach. Several students indicated that there is nothing to be changed in the science and engineering practices activities while some students suggested for more time to better improve and implement their designs. Finally, few students suggested the need for minimizing the constraints indicated in the activities.

CHAPTER V

CONCLUSIONS AND DISCUSSION

This study investigated the following research questions: (a) What are the effects of implementing scientific and engineering practices as compared to structured inquiry in teaching about cellular biology on eighth grade students' achievement? (b) What are the effects of implementing scientific and engineering practices as compared to structured-inquiry on eighth grade students' attitudes toward biology? (c) What are the effects of implementing scientific and engineering design practices in teaching about cellular biology on eighth grade students 'design skills.

This chapter is organized as follows: the first section presents a summary of the quantitative and qualitative results of both groups. The second section represents the results of students' attitudes towards biology. The third section represents the results of students' interviews and their opinions toward biology. The fourth section presents a summary of the qualitative results of students' engineering design skills. Each of these sections is followed by discussing the results. The final section of this chapter presents the limitations of this study and implications to practice, students, science teachers, and curriculum designers.

5.1. Students' Achievement in Biology

The results of the first and second concept tests showed that students in the control group achieved higher than those in the experimental group but the difference was not significant. This result aligns with previous literature on using guided versus unguided inquiry activities - which included using science and engineering practices- that showed conflicting findings concerning students' achievement upon intervention. Out of the many studies performed to investigate the effect of different types of inquiry on students' achievement, some suggest that the use of inquiry is effective in enhancing student learning (Anderson, 2002; Sesen & Tarhan, 2011;Supasorn & Lordkam, 2014; Wilhelm & Wilhelm, 2010) while others suggest that partially-guided or unguided inquiry, such as using science and engineering practices, is effective only for experienced students and not for inexperienced ones since it leads to cognitive overload (Alfieri et al., 2011; Clark et al., 2012; Kalyuga, 2012). Moreover, many studies suggest that inquiry teaching does not improve learning for all students consistently (e.g., Alfieri et al., 2011; Chase et al., 2013; Clark et al., 2012; Kalyuga, 2012 ; Mastropieri et al., 1997). Apparently, the grade 8 students who participated in this study were not experienced enough to benefit from the intervention that used science and engineering practices to the extent advocated in some research studies.

It is important to note that the dependent samples t-tests showed that both groups achieved significantly higher in the two post concept test and that their scores on the post-tests were very similar. This indicates that student in both groups: the structured inquiry group and the science and engineering practices group benefited equally from the two approaches. One explanation for these results is that the claim that involving student in science and engineering practices group will benefit them more than being involved in structured inquiry is not tenable, at least for this group of grade 8 students. This conclusion is supported by the responses of students in both groups to the interview questions in which the structured inquiry group said that they benefited from being involved in the activities and also student in the science and engineering practices group said that they also benefited from the activities. It is possible that students in both groups benefited from the hands-on activities in which they were involved, irrespective if these activities were of the structured or the science and engineering practices type.

The supplementary analyses that were used to examine the two-tier type questions used in the two concept tests showed that students' performance improved on the following topics in the first concept test for the control group: Definition of a cell, Prokaryotic cells, function of the nucleus, and plant versus animal cells while they did not improve on definition of a cell. In the experimental group, students' performance improved on the following concepts: definition of a cell, building blocks of cells, Prokaryotic cells, function of the nucleus, Plant versus animal cells. However, it is worth noting that students' responses to items about prokaryotic cells and function of the nucleus improved significantly for both groups. When considering the second concept tests, students' performance in control group improved on all topics except for the concentration gradient versus diffusion rate while students' performance in the experimental group improved for all topics except for the process of diffusion where the number of students who had problems stayed the same. However, it is noticed that even though there was improvement on most topics included in concept test 2, around 50% of the students had problems with the following topics: example of diffusion, process of diffusion, equilibrium, concentration gradient versus diffusion rate, effect of hypertonic solutions on cells, and osmosis as passive transport. One explanation for this finding could be related to the abstract nature of the concepts and the need for students to understand the interplay between the micro and the macro level processes. Another possible explanation of the results could be the match between the type of activity and the type of practice that it requires, a claim that needs to be investigated further.

Furthermore, the results of the first and second achievement tests showed that students in the experimental group achieved higher than the control group but the differences were not significant This could be attributed to the fact that teaching engineering design to grade 8 students requires scaffolding strategies that promote critical thinking skills and eliminate the obstacles faced by students and teachers (Bamberger & Cahill, 2013; Mehalik, Doppelt & Schuun, 2008); something that was not done with students who participated in this study.

In contrast, the results of the first achievement test show that students in the experimental group achieved significantly higher in the high cognitive level questions than the control group. This finding could be explained by the fact that students perform better in science when analytical writing is involved. It is worth noting that students in the experimental group were required to write an analytical essay in which they had to compare the elements of any system (school, city…) to the cell and its organelles (Refer to cell analogy project in Appendix C). Rivard and Straw (1999) explain that analytical writing helps students to better organize their acquired knowledge thus leading to better retention. Moreover, this could be attributed to the fact that writing in science promotes conceptual understanding and possible conceptual change (Rivard & Straw, 1999). Furthermore, this can also be due to the fact that the cell analogy project adapted from the NGSS included scaffolding with explicit instructions for the experimental students, thus helping some of them to develop a deeper understanding of the concepts being taught. This finding aligns with a previous research which discussed that scaffolding can enhance students' meta-cognitive processes, inquiry skills and content knowledge (McNeill, Krajcik, Lizotte & Marx 2006). Similarly, Hohenshell and Hand (2006) explains that "guidance in planning during portions of the writing process combined with the opportunities to discuss idea appear to be important pedagogical components to facilitate learning through writing" (p.264). It is important to note that the statistically significant result could be by chance especially that it was the only significant finding among others that were not.

The lack of significant results in the second achievement test could be due to the lack of students' exposure to engineering design in biology. Consequently, engaging students in design thinking for a sufficient amount of time is necessary for conceptual understanding to occur. In addition, the short-term duration of the intervention may have influenced the results. For example, to get positive results, Hokayem and Schwartz (2014) conducted a study for a period of 8 weeks while students in this study had only 5 weeks to complete the unit on cellular biology. An alternative explanation for the results could be attributed to the fact that students in both groups benefited equally form the structured inquiry and the science and engineering practices because they both involved students in hands on activities. Thus, a similar argument to the one used above to explain the results of the pre and post-concept tests could be used here.

5.2. Students' Attitudes toward Biology

The results of the pre-post attitude scale showed that there were no significant differences regarding students' attitudes towards biology between the two groups. This reason for the lack of significant could be 1) the short duration of the study, 2) the fact that both groups used inquiry learning even though the approaches were different. Common elements between the two approaches (such as the interactivity, student-centered learning approach, hands-on activities, teacher guidance, and collaborative learning….) could be the factor that influenced students' attitudes. Therefore, it might have been because the two approaches were interactive, student-centered, involve hands-on activities, and because the teacher in both groups modeled the activities and continuously provided guidance, there were no significant differences between the two groups regarding their attitudes towards biology. The different elements between the two approaches (in specific, the level of inquiry, inquiry levels and incorporation of NGSS science and engineering practices) seem to have no effect on students' attitudes towards biology. More importantly however, the results of the Biology Attitude Scale may have been influenced by the low reliability of the Equipment subscale (α=0.36) and the difficulty subscale (α=0.46) in the questionnaire even though the overall reliability was 0.87.

One other factor that might have contributed the results is the fact that the students in both groups frequently complained about memorizing the material required and asked whether the NGSS activities are included in the test and what parts they should memorize. The reason is that most students face difficulties when learning concepts related to cellular biology (Riemeier & Gropengießer 2008).

5.3. Students' interviews

The majority of students in both groups found the instructional approaches helpful and expressed that they would like to use them in future work in biology. This may be attributed to the fact that students in both groups were engaged in hands-on activities. While, most students in the structured inquiry group said that the instructional approach did not encourage them to be creative due to explicit instructions, many students in the science and engineering practices group said that the science and engineering practices approach allowed them to use their creativity. These findings align with previous research which showed that engaging students in such programs has a positive impact on their conceptions of engineering and increase their interest in science (Daugherty, 2012 as cited in Lakose 2015; Hammak et al., 2015).

In contrast to the structured-inquiry group, the majority of students in the science and engineering practices group found it challenging. This might have been because the engineering design process did not include scaffolding of steps or explicit guidelines for the different stages of the engineering design process. This also resonates with Zhou et al. (2017) who noted that students at the middle school level face critical challenges when involved in engineering design. Unlike the structured-inquiry group, most students in the science and engineering practices said that they gained knowledge and skills rather than just knowledge. This aligns with the findings of Cunningham and Carslen (2017) who highlighted that student engagement in engineering design practices could improve their knowledge acquisition skills. This may also be attributed to the fact that students in the science and engineering practices group were involved in researching, planning, constructing, and testing the designs. Finally, the students in the science and engineering practices group suggested the need for a longer time in order to accurately improve and test their designs. However, this suggestion has not been highlighted by students in the structured-inquiry group. This finding resonates with Sadler, Coyle and Schwartz (2000) who suggest that students need at least 5 to 10 hours for building and testing their designs.

5.4. Students' Proficiency Level in Engineering Design Skills

In addition to examining students' achievement in biology, an engineering design task assessment was used to analyze students' proficiency level in engineering design skills. Students' responses were categorized as proficient, developing, beginners or novice. Results showed that the majority of students in both groups were at level 3 (proficient) in the questions related to the assessment of design. However; the number of students at level 3 (proficient) in the experimental group in these questions was considerably higher than the control group. Also, the number of students at level 3 in the question related to functionality of design was higher, than those in the control group. Similarly, the number of students at level 2 (developing) in the experimental group was higher than those in the control group. These findings align with previous research which indicates that engaging students' in engineering design activities improves their design skills (Ercan & Sahin, 2015; Hammak et al., 2015).

However, students' engineering design skills in the question related to explanation of design testing revealed that the number of students at level 3 (proficient) in the control group is relatively close to that of the experimental group. In addition, the number of students at level 0 (novice) in the experimental group is slightly higher than in the control group. According to Hynes (2012), teachers are less proficient in teaching design testing, a fact that might have influenced the performance of both groups.

Another reason could be the short duration of the intervention. Sadler et al. (2000) explained that middle school students require a prolonged period of testing and construction for the engineering design approach to be effective. It can also be attributed to the developmental level of middle school students who have not developed the higher order skills needed to assess design activities. (Zhou et al., 2017).

5.5. Implications

This study has major implications to research and practice. More empirical studies are needed to investigate the effect of NGSS science and engineering practices on students' achievement, attitudes toward biology, and engineering design skills. This is because this type of research has not been prevalent in science education. Moreover, research is needed on the effect of implementing NGSS science and engineering practices on students' attitudes toward science, especially that NGSS claims that using science and engineering practice improves achievement and attitudes toward science (Moore, Tank, Glancy, & Kersten, 2015).

The results of this study are important for science teachers, school administrators, and curriculum designers. The effectiveness of the NGSS science and engineering design practices on students' high level cognitive thinking and on specific engineering design skills leads to the assumption that students will learn better in student-centered classrooms supported with an NGSS science and engineering practices approach. Consequently, teachers and other school administrators might consider this finding when planning to integrate NGSS science and engineering practices in teaching subject matter. Moreover, curriculum designers can design curricular materials based on certain criteria hence bridging the gap between practical and educational support.

Moreover, previous research showed that it is important involving students in science and engineering practices should start at an early age even if students can only reason when given guided activities. In addition, more professional development is required to better prepare elementary and middle school teachers for implementing science and engineering design (Cunningham, 2009; Hynes, 2012).

5.6. Limitations

One of the limitations of this study is the time factor. The short implementation time might have influenced the possible benefits that one can expect from a longer involvement of students in the science and engineering practices approach, especially regarding attitudes toward and achievement in biology. Moreover, the research cannot be generalized because of the short duration and the relatively small number of students. Consequently, more research is needed to design the appropriate engineering design and science practices materials and implement them properly in a variety of topics to improve students' achievement, skills and attitudes toward biology. Another possible limitation of this study is the fact that scaffolding was not incorporated in all the activities except for one.

APPENDICES

APPENDIX A

EXPERIMENTAL GROUP LESSON PLANS

Introducing Science and Engineering Practices and Benzene Ring Heuristic

(First Session)

Purpose

This lesson will introduce the students to NGSS science and engineering practices. They will explore the meaning of science and engineering practices and their various components based on the Benzene Ring Heuristic (BRH). The lesson will allow the students to identify the different components of science and engineering practices and use them in their science lessons.

Science Content and Major Concepts

The students will be introduced to the BRH of science practices and its various components (content is attached in Appendix C)

Instructional objectives

By the end of the lesson, the students will be able to:

- Define NGSS science and engineering practices
- Identify the components of science and engineering practices based on BRH
- Develop their science practices and engineering skills

Pre-requisite Abilities

The lesson does not require any pre-requisite abilities to achieve its objectives because it's not directly related to the content of the unit. The lesson focuses on a general science topic on diffusion of ink in hot and cold water which is related to the students' daily lives

Materials and Equipment

Handouts (Appendix C)

Instructional Activities

Set Induction. The teacher will first implement a brief activity that was developed by the teacher and the researcher.In this brainstorming activity, students will reflect on their different perceptions of science and engineering practices. Students in groups will be asked to develop a list of their initial notions of science and engineering practices, construct concept maps to link their ideas and present them. During the presentations, the teacher will highlight the common perceptions of science and engineering practices based on the students' responses. The teacher will then define science and engineering practices and will relate them to the field of science. The teacher will explain that the idea that we hold about the scientific method as the only linear process for the establishment of scientific facts is no longer valid. In science and engineering, ideas are established through the use of NGSS science and engineering practices in a circular and non-specific sequence represented by the model of the Benzene Ring Heuristic (BRH).The various components of science practices will be defined and the students will receive a handout (Appendix C) that includes information describing each component along with a diagram of BRH.

Other Instructional Activities. The teacher will then explicitly introduce the Benzene Ring Heuristic (BRH) of the NGSS science and engineering practices through a activity similar to the instructional activities conducted by Krajcik and Merritt (2012) (Appendix C). The BRH will be chosen to be introduced explicitly because it is a significant starting point for intermediate level students to get acquainted with the science and engineering practices. In this activity, students in groups will be asked to draw and label a model related to the diffusion of blue ink in hot and cold water. They will then be asked to work individually in an attempt to draw pictures that will illustrate what happens between the water molecules and ink particles. Afterwards, the teacher will distribute a copy of BRH and ask the students to link the ideas in the heuristic to the diffusion of ink activity that they have just conducted. They will then discuss their pictures in order to evaluate the adequacy of each other's models before a whole classroom discussion that will be conducted. The aim of these discussions will be for students to actually realize that a single activity might engage them in several components of science practices integrated in a non-specific and complex sequence. The teacher will guide the discussions in such a way that the various components of science practices will get revealed. He will then illustrate a structured diagram of the discussed activity and fill in the various components of science practices to familiarize the students with the meanings of scientific terms.

Assessment of Instructional Objectives

In this lesson, the students' understanding of science practices and its components will be informally assessed during the classroom discussion. The students' understanding of science practices will be further assessed during the following sessions.

Cellular Organelles (Second and Third Session)

Purpose

The purpose of this lesson is to develop students' understanding of the concepts of the cellular structure and function. The lesson will develop students' content knowledge of the different types of cells and the structure and function of cellular organelles. The students develop their ideas through guided inquiry-based research by answering specific questions related to the topic.

Science content and major concepts

The content presented in the lesson includes information about cellular structure and function (Electronic Textbook, visual aids, animations) and the cell questions sheet (Appendix C). The core ideas are the following (Appendix E, NGSS Lead States, 2013):

LS1. A
All living things are made up of cells. In organisms, cells work together to form tissues and organs that are specialized for particular body functions.

Instructional objectives

By the end of the lessons, the students will be able to:

- Describe the basic structures and functions of cells.
- List the two major categories of cells. Explain the difference and give examples.
- Define an organelle.
- Compare and contrast a plant cell and an animal cell.
- Label an animal cell and a plant cell.
- Explain the function of each of the following structures: nucleus, nucleolus, nuclear membrane, cytoplasm, ribosome, lysosome, vacuole, smooth endoplasmic reticulum, rough endoplasmic reticulum, Golgi body, mitochondrion, chloroplast, cell membrane and cell wall.
- Differentiate between the smooth endoplasmic reticulum and rough endoplasmic reticulum.

Pre-requisite Abilities

Students must be familiar with the following core ideas:

LS1.A All organisms have external parts that they use to perform daily functions.

LS 1.A Organisms have both internal and external macroscopic structures that allow for growth, survival, behavior, and reproduction.

Materials and Equipment

Electronic Textbook, laptops, internet access and questions sheet (Appendix C).

Instructional Activities

At the beginning of the session, the teacher will display a set of questions that need to be answer by the students' in the coming two blocks. The students' will be asked to make use of several recommended websites and interactive animations on Moodle.

Closure and Review. At the end of the lesson, the displayed questions about cells and cellular structure will be discussed. The students' responses as a result of their guided research were linked to the questions. The students will also be asked to review the material covered in every class in order to complete an activity in the coming block. Students will also be asked to submit their answers on Google docs to be checked by the teacher.

Assessment of Instructional Objectives

In this lesson the students understanding of cells and cellular structure will be assessed informally through classroom discussion and by checking the students' answers.

Cell Analogy (Fourth and Fifth Session)

Purpose

The purpose of this lesson is to enhance students' understanding of the concept of cellular structure and function. The activity used will develop the students' science practices skills (e.g. modeling) in the understanding of cellular organelles.

Science content and major concepts

The content presented in the lesson includes information about cellular structure and function (Electronic Textbook, animations and visual aids on Moodle). The NGSS standards and core ideas respectively include the following (Appendix E, NGSS Lead States, 2013):

- Develop and Use a model to describe the function of a cell as a whole and ways parts of cells contribute to their function.
- Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.

Instructional objectives

By the end of the lesson, the students will be able to:

- Understand the structure and function of a cell.
- Compare a cell to a specific system.

Pre-requisite Abilities

Students must be familiar with the structure and function of different organelles and components of science practices.

Materials and Equipment

Activity Handout (Appendix C), Laptop, internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will remind the students of the structure and functions of different organelles through a short animation. The student's will then be divided in groups of two and will be asked to choose a topic or a system that they would like to compare a cell to where no two topics must be the same.

Other Instructional Activities. Students will be asked to complete the NGSS Cell analogy Activity in the coming two blocks

Closure and Review. At the end of the lesson, the teacher asked the students' to share their work on google docs to receive more feedback from the teacher.

Assessment of Instructional Objectives

In this lesson, the students' acquired science practices skills and understanding of cell structure and function will be assessed informally during the classroom discussion and by checking the students' work.

Cellular Transport (Sixth and Seventh Session)

Purpose

The purpose of this lesson is to enhance students' understanding of cellular transport. The lesson will develop the students' understanding of passive transport and its different types.

Science content and major concepts

The content presented in the lesson includes information about cellular transport (Electronic Textbook, visual aids, animations) and. The Concepts are the following:

- Cell membrane
- Active and Passive Transport
- Diffusion and Osmosis
- Equilibrium
- Concentration Gradient

Instructional objectives

By the end of the lesson, the students will be able to:

- Explain the structure of the cell membrane.
- State the difference between active and passive transport across the membrane
- List the types of passive transport
- Explain how each type of passive transport work

Pre-requisite Abilities

Students must be familiar with cell structure and function.

Materials and Equipment

Laptop and internet access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will remind the students about the function of the cell membrane and its important role in controlling the transport of materials in and out of the cell.

Other Instructional Activities. The students will learn concepts using a variety of student-centered approaches. The students will be taking notes from the ones written by the teacher or from the animations and videos watched.

Closure and Review. At the end of the lesson, the students' will be asked to answer an interactive quiz on passive transport and their answers will be discussed.

Assessment of Instructional Objectives

In this lesson, the students' acquired science practices skills and understanding of cellular respiration will be assessed informally during the classroom discussion.

Active Cellular Transport (Eighth Session)

Purpose

The purpose of this lesson is to enhance students' understanding of cellular transport. The lesson will develop the students' understanding of active transport and their different types.

Science content and major concepts

- Active Transport
- Endocytosis
- Exocytosis
- Cell Energy (ATP)

Instructional objectives

By the end of the lesson, the students will be able to:

- List the types of active transport
- Explain how each type of active transport work
- State the difference between active and passive transport across the membrane.

Pre-requisite Abilities

Students must be familiar with cell structure and function.

Materials and Equipment

Laptop, Internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will introduce the topic of active transport and explain what it means.

Other Instructional Activities. The students will develop the concepts using a variety of student-centered approaches. The students will be taking notes from the ones written by the teacher or from the animations and videos displayed.

Closure and Review. At the end of the lesson, the students' will be asked to answer an interactive quiz on active transport and their answers will be discussed.

Assessment of Instructional Objectives

In this lesson, the students' acquired science practices skills and understanding of cellular transport will be assessed informally during classroom discussion.

Red Rover Activity (Ninth Session)

Purpose

The purpose of this lesson is to develop students' understanding of the different types of cellular transport. The activity used will develop the students' science practices skills (e.g. modeling) in the understanding of cellular transport.

Science content and major concepts

The content presented in the lesson includes information about cellular structure and function (animations and visual aids). The NGSS standards and core ideas respectively include:

- Develop and use a model to illustrate the hierarchical organizations of interacting systems that provide specific functions within multicellular organisms.
- Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.

Instructional objectives

By the end of the lesson, the students will be able to:

- Act as a different particle or part of the cell membrane to model active and passive transport.
- Explain how particles are transported from one side of the cell membrane to the other.

Pre-requisite Abilities

Students must be familiar with the structure and function of cellular organelles, active and passive transport, ions and molecules.

Materials and Equipment

Activity Handout (Appendix C), Laptop, internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will remind the students of the different types of cellular transport through a short animation. The student's will then be divided in groups of four or five and will be asked to choose a card that display ions, molecules or cell membrane member.

Other Instructional Activities. Students will be asked to complete the NGSS red rover activity in their groups. During the activity, the teacher will discuss the modeling behavior of every student in order to ensure the understanding the different types of cellular transport.

Closure and Review. At the end of the lesson, the teacher asked the students' to complete a short formative assessment (Appendix C).

Assessment of Instructional Objectives

In this lesson, the students' acquired science practices skills and understanding of cellular transport will be assessed informally during the classroom discussion and by checking their answers on the formative assessment.

Cellular Transport Engineering and Design (Tenth, Eleven and Twelve)

The purpose of this lesson is to further develop students' understanding of osmosis and diffusion. The activity used will develop the students' science practices and engineering skills in the understanding of passive transport.

Science content and major concepts

The content presented in the lesson include information about cellular structure and function (animations and visual aids). The Core ideas respectively include:

- Defining and Delimiting an Engineering Problem: Attend to precision of criteria and constraints and considerations likely to limit possible solutions.
- Developing Possible Solutions: Combine parts of different solutions to create new solutions
- Optimizing the Design Solutions: Use systematic processes to iteratively test and refine a solution

Performance Expectations

By the end of the lesson, the students will be able to (Appendix I):

- Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principle and potential impacts on people and the natural environment that may limit possible solutions.
- Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Pre-requisite Abilities

Students must be familiar with the concepts of diffusion and Osmosis.

Materials and Equipment

Activity Handout (Appendix C), lab materials Laptop, internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will remind the students about diffusion and Osmosis through a short animation. The student's will then be divided in groups of two in order to complete an engineering design activity (Appendix C). They will then be asked to choose between two topics which are diffusion and osmosis to design their setup.

Other Instructional Activities. In the first block, students have to research to come up with the design of the setup that they have opted for and sketch a labeled diagram of their design. In the second block, students had to build their setup using the list of materials and then they had to evaluate and test their setup for accuracy and function in the last block.

Assessment of Instructional Objectives

In this lesson, the students' acquired science and engineering design skills and understanding of passive transport will be assessed informally during the students' feedback through the engineering activity.

APPENDIX B

CONTROL GROUP LESSON PLANS

Introducing Inquiry and the Scientific Method (First Session)

Purpose

This lesson will introduce the students to Inquiry and Scientific Method. They will explore the meaning of inquiry and the components of the scientific method. The lesson will allow the students to identify the different components of the scientific method and use them in their science lessons.

Science Content and Major Concepts

The students will be introduced to the inquiry scientific method and its various components (content is attached in Appendix C)

Instructional objectives

By the end of the lesson, the students will be able to:

- Identify the essential components of inquiry based on the scientific method
- Develop their Inquiry skills

Pre-requisite Abilities

The lesson does not require any pre-requisite abilities to achieve its objectives because it’s not directly related to the content of the unit. The lesson focuses on a general science topic on diffusion water at different which is related to the students’ daily lives

Materials and Equipment

Handouts (Appendix C)

Instructional Activities

Set Induction. The teacher will first implement a brief activity that was developed by the teacher and the researcher. In this brainstorming activity, students will reflect on their different perceptions of inquiry. Students in groups will be asked to develop a list of their initial notions of scientific inquiry, construct concept maps to link their ideas and present them briefly. During the presentations, the teacher will highlight the common perceptions of inquiry based on the students’ responses. The teacher will then explain the scientific inquiry and scientific method. The various components of scientific method will be explained and the students will receive a handout (Appendix C) that includes information about the essential components of inquiry and a diagram that illustrates the scientific method.

Other Instructional Activities. The teacher will then explicitly introduce the inquiry scientific method through a diffusion activity (Appendix C).In this activity, students will be asked to collect data related to the diffusion of blue ink in hot and cold water based on a given procedure. They will then be asked to work individually in an attempt to record their observations, analyze their results and draw conclusions. Afterwards, the teacher will distribute a copy of scientific method diagram and ask the students to link the ideas in the diagram to the diffusion of ink activity that they have just conducted.

Assessment of Instructional Objectives

In this lesson, the students' understanding of inquiry scientific method and its components will be informally assessed during the classroom discussion. The students' understanding of inquiry scientific method will be further assessed during the following sessions.

Cellular Organelles (Second and Third Session)

Purpose

The purpose of this lesson is to develop students' understanding of the concepts of the cell structure and function. The lesson will develop students' content knowledge of the different types of cells and the structure and function of cellular organelles. The students develop their ideas through guided inquiry-based research by answering specific questions related to the topic.

Science content and major concepts

The content presented in the lesson includes information about cellular organelles (Electronic Textbook, visual aids, and animations on Moodle) and the cell questions sheet (Appendix C).

Instructional objectives

By the end of the lessons, the students will be able to:

- Describe the basic structures and functions of cells.
- List the two major categories of cells. Explain the difference and give examples.
- Define an organelle.
- Compare and contrast a plant cell and an animal cell.
- Label an animal cell and a plant cell.
- Explain the function of each of the following structures: nucleus, nucleolus, nuclear membrane, cytoplasm, ribosome, lysosomes, vacuole, smooth endoplasmic reticulum, rough endoplasmic reticulum, Golgi body, mitochondrion, chloroplast, cell membrane and cell wall.
- Differentiate between the structure of smooth endoplasmic reticulum and rough endoplasmic reticulum.

Pre-requisite Abilities

Students must be familiar with the following core ideas:

LS1.A All organisms have external parts that they use to perform daily functions.

LS 1.A Organisms have both internal and external macroscopic structures that allow for growth, survival, behavior, and reproduction.

Materials and Equipment

Electronic Textbook, laptops, internet access and questions sheet (Appendix C).

Instructional Activities

At the beginning of the session, the teacher will display a set of questions that need to be answer by the students' in the coming two blocks. The students' will be asked to make use of several recommended sites and interactive animations on Moodle.

Closure and Review. At the end of the lesson, the displayed questions about cells and cellular structure were discussed. The students' responses as a result of their guided research were linked to the questions. The students will also be asked to review the material covered in every class in order to complete an activity in the coming block. Students will also be asked to submit their answers on Google docs to be checked by the teacher.

Assessment of Instructional Objectives

In this lesson the students understanding of cells and cellular structure will be assessed informally.

Cells and Organelles (Fourth and fifth Session)

Purpose

The purpose of this activity is to enhance students' understanding of the concept of cells and cellular organelles. The lesson will reinforce the students' content knowledge of cellular organelles and will introduce them to cell analogy.

Science Content and Major Concepts

The content presented within this lesson includes information about cells and organelles (Found in the Electronic Textbook, visual aids and animations on Moodle).

Instructional Objectives

By the end of the lesson, the students will be able to:

- Reinforce their conceptions of cells and organelles

-Explore different cell analogies

Pre-requisite Abilities

Students must be familiar with the concepts of cells and cellular organelles.

Materials and Equipment

Laptops with internet access and prepared worksheet (Appendix C)

Instructional Activities

Set induction. Early at the beginning of this session, the teacher will remind the students briefly of the previously discussed information about the different types of cells and organelles. The teacher will then state that this session allows the students to further explore the structure and function of organelles, plant versus animal cells and cellular analogy.

Other instructional activities. The students are then asked to solve two worksheets in pairs through inquiry-based research. Afterwards, the worksheet questions will be corrected in class, and the students will be given a chance to share and explain their responses.

Closure and review. The teacher will summarize major concepts discussed during the session.

Assessment of Instructional Objectives

In this lesson, the students' acquired content knowledge of the topic is assessed informally through classroom discussion and by checking the students' answers.

Passive Cellular Transport (Sixth and Seventh Session)

Purpose

The purpose of this lesson is to enhance students' understanding of cellular transport. The lesson will develop the students' understanding of passive transport and their different types.

Science content and major concepts

The content presented in the lesson includes information about cellular transport (Electronic Textbook, visual aids, animations) and. The Concepts are the following:

- Cell membrane
- Active and Passive Transport
- Diffusion and Osmosis
- Equilibrium

Instructional objectives

By the end of the lesson, the students will be able to:

- Explain the structure of the cell membrane.
- State the difference between active and passive transport across the membrane
- List the types of passive transport
- Explain how each type of passive transport work
- Distinguish between hypotonic, isotonic and hypertonic solutions and explain their effect on plant and animal cells.

Pre-requisite Abilities

Students must be familiar with cell structure and function.

Materials and Equipment

Laptop and internet access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will introduce the new topic of cellular transport and explain what cellular transport means. He will then display a video on the concepts related to the topic and the concepts that need to be covered.

Other Instructional Activities. The students will concepts using a variety of student-centered approaches. The students will be taking notes from the ones written by the teacher or from the animations and videos watched.

Closure and Review. At the end of the lesson, the students' will be asked to answer an interactive quiz on passive transport and their answers will be discussed.

Assessment of Instructional Objectives

In this lesson, the students' understanding of passive cellular transport will be assessed informally during the classroom discussion.

Active Cellular Transport (Eighth Session)

Purpose

The purpose of this lesson is to enhance students' understanding of cellular transport. The lesson will develop the students' understanding of active transport and their different types.

Science content and major concepts

- Active Transport
- Endocytosis
- Exocytosis
- Cell Energy (ATP)

Instructional objectives

By the end of the lesson, the students will be able to:

- List the types of active transport
- Explain how each type of active transport work
- State the difference between active and passive transport across the membrane.

Pre-requisite Abilities

Students must be familiar with cell structure and function.

Materials and Equipment

Laptop, Internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will introduce the new topic of active transport and explain what it means. He will then display a video on the concepts related to the topic and the concepts that need to be covered.

Other Instructional Activities. The students will learn the concepts using a variety of student-centered approaches. The students will be taking notes from the ones written by the teacher or from the animations and videos displayed.

Closure and Review. At the end of the lesson, the students' will be asked to answer an interactive quiz on active transport and their answers will be discussed.

Assessment of Instructional Objectives

In this lesson, the students' understanding of active cellular transport will be assessed informally during classroom discussion.

Cellular Transport (Ninth Session and Twelfth)

Purpose
The purpose of this activity is to enhance students' understanding of the concept of cellular transport. The lesson will reinforce the students' content knowledge of cellular transport.

Science Content and Major Concepts
The content presented within this lesson includes information about cellular transport (Found in the Electronic Textbook, visual aids and animations on Moodle).

Instructional Objectives
By the end of the lesson, the students will be able to:
- Reinforce their conceptions of active and passive transport
-Differentiate between hypotonic, isotonic and hypertonic solutions and explain their effect on plant and animal cells.
- **Pre-requisite Abilities**
Students must be familiar with the concepts of passive and active transport
Materials and Equipment

Laptops, internet access and prepared worksheet (Appendix C)

Instructional Activities
Set induction. Early at the beginning of this session, the teacher will remind the students briefly of the previously discussed information about the active and passive cellular transport. The teacher will then state that this session allows the students to further explore the different types of cellular transport.

Other instructional activities. The students are then asked to solve the worksheet in pairs through inquiry-based research. Afterwards, the worksheet questions will be corrected in class, and the students will be given a chance to share and explain their responses.

Closure and review. The teacher will summarize major concepts discussed during the session.

Assessment of Instructional Objectives
In this lesson, the students' acquired content knowledge of the topic is assessed informally through classroom discussion.

Potato Osmosis Lab Activity (Tenth and Eleventh)

Purpose

The purpose of this lesson is to enhance students' understanding of the concept of osmosis. The lesson will develop students' content knowledge of osmosis. The lab activity used will develop the students' scientific inquiry skills (e.g. collecting data, analyzing data and drawing conclusions) in the understanding of osmosis.

Science content and major concepts

The content presented in the lesson include information about osmosis (Electronic Textbook, animations and visual aids on Moodle, osmosis

Instructional objectives

By the end of the lesson, the students will be able to:

- Indicate which molecules move by osmosis.
- Define hypotonic, isotonic and hypertonic solutions and explain their effect on plant cells.
- Determine changes in masses of potato caused by osmosis.

Pre-requisite Abilities

Students must be familiar with different types of passive transport.

Materials and Equipment

Lab Activity Handout (Appendix C), Laptop, internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will remind the students of the different types of passive transport through a short animation. The student's will then be divided in groups of two or three and will be asked to read the potato osmosis lab sheet.

Other Instructional Activities. The students will then be asked to complete the potato-osmosis lab activity.

Closure and Review. At the end of the lesson, the teacher asked the students' to share their data and explain their responses.

Assessment of Instructional Objectives

In this lesson, the students' acquired scientific inquiry skills and understanding of osmosis will be assessed informally during the classroom discussion and by checking their lab questions.

Passive transport and Bag Lab Activity (Eleventh and Twelfth)

Purpose

The purpose of this lesson is to enhance students' understanding of diffusion and osmosis. The lesson will develop students' content knowledge of the two types of passive transport. The lab activity used will develop the students' scientific inquiry skills (e.g. collecting data, analyzing data and drawing conclusions) in the understanding of diffusion versus osmosis.

Science content and major concepts

The content presented in the lesson include information about diffusion (Electronic Textbook, animations and visual aids on Moodle)

Instructional objectives

By the end of the lesson, the students will be able to:

- Predict net movement of molecules across a semi-permeable membrane
- Indicate which molecules move during diffusion and osmosis
- Determine changes in volume caused by osmosis
- Determine change in mass caused by diffusion
- Define hypertonic, hypotonic and isotonic solutions

Pre-requisite Abilities

Students must be familiar with osmosis and diffusion

Materials and Equipment

Lab Activity Handout (Appendix C), Laptop, internet Access

Instructional Activities

Set Induction. At the beginning of the session, the teacher will remind the students of the different types of passive transport through a short animation. The student's will then be divided in groups of two or three and will be asked to read the passive transport and bag lab sheet (Appendix C) .

Other Instructional Activities. The students will then be asked to complete the diffusion and bag activity.

Closure and Review. At the end of the lesson, the teacher asked the students' to share their data and explain their responses.

Assessment of Instructional Objectives

In this lesson, the students' acquired scientific inquiry skills and understanding of diffusion and osmosis will be assessed informally during the classroom discussion and by checking their answers on lab questions.

APPENDIX C

EXPERIMENTAL GROUP WORKSHEETS

Benzene Ring Heuristic (BRH) of NGSS Science Practices (First session)

Erduran and Dagher (2014) discussed that the BRH of NGSS science practices consist of the following ten components:

- Real World: The physical world in which scientific investigations take place.
- Activities: Include purposeful classification, observation, and/or experimentation.
- Data: Data could be generated (first-hand) or obtained from science archives (second-hand)
- Model: Should 1) be based on data; 2) explain and predict phenomena; 3) provide a representation.
- Explanation: Permits understanding of phenomena and underlying mechanisms.
- Prediction: Anticipates future occurrences or events based on knowledge for underlying mechanisms.
- Representation: Conceptual, mathematical, computational, physical or visual illustration.
- Argumentation/ Reasoning: The process of formulating/providing evidence based arguments to support claims.
- Discourse: The language and context associated with dialogue in an activity.
- Social certification: The processes of reviewing and evaluating claims from different perspectives among peers in a social setting.

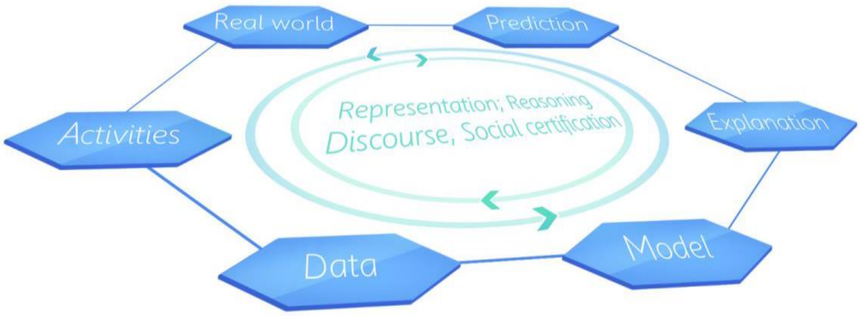

Figure. Benzene Ring Heuristic (Erduran & Dagher, 2014, p.82)

Food coloring & Water Activity

Materials per group

- **Two 250 ml beakers**
- **Graduated cylinders 100ml**
- **blue Food coloring**
- **droppers**
- **hotplate**
- **Markers**

Question:

What do you think will happen if we add few drops of food coloring into cold water versus hot water? What is your hypothesis?

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Use the following instructions to test your hypothesis:

1. Label your beakers 1 & 2
2. Add 100 ml of water to each beaker (1 & 2)
3. Place beaker 2 on the hotplate to heat it for around 5 minutes
4. Add 4 drops of food coloring to the water in beaker 1. Observe what happens.
5. Add 4 drops of food coloring to the water in beaker 2. Observe what happens.
6. Describe your observations in the spaces below.

A. Observations of beaker 1 (cold water & food coloring).

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B. Observations of beaker 2 (hot water & food coloring).

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C. Imagine you have a special instrument that allows you to see what happens to the food coloring particles in cold and hot water.
    1. Construct a model below to illustrate what happens to food coloring particles in beaker 1 containing cold water based on evidence from your observations. <u>Label the different parts of your model so that someone looking at it will know what the parts represent.</u>

    2. Construct a model below to illustrate what happens to food coloring particles in beaker 2 (hot water) based on evidence from your observations. <u>Label the different parts of your model so that someone looking at it will know what the parts represent.</u>

Cell questions sheet

1. Define a cell?
2. What are the two general categories of cells?
3. What is the difference between prokaryotic and eukaryotic cells? Give examples of each
4. State the function of each of the following:
    i. Nucleus
    ii. Cell membrane
    iii. Golgi apparatus
    iv. Endoplasmic reticulum
    v. Mitochondria
    vi. Chloroplast
    vii. ribosomes
    viii. cytoplasm

Cell Analogy Project

Objective: Your goal is to create an analogy that relates to a eukaryotic cell. Your final product is a story about something that has similarities to a cell's structure. There are 9 main parts to an animal cell.

1. Cell membrane
2. Nucleus
3. Nucleolus
4. mitochondria
5. ribosomes
6. Rough Endoplasmic Reticulum
7. Smooth Endoplasmic reticulum
8. Golgi apparatus
9. lysosomes

Definition of Analogy: A similarity between two things that are otherwise unlike. For example the motor in a car is analogous to a power plant, since they are both used to produce power.

Topics: Every group need to have their own analogy. No two analogies can be the same. To start, your topic needs to be complex. Second, it is easier if it a place or thing. Examples of topics: castle, mall, Hogwarts, Bikini Bottom, school, New York City (NYC), concert hall, car, football stadium, cruise, ship, hospital, USA, restaurant, factory… etc.

Paragraphs: Each paragraph should be about one of the 9 parts assigned. There should be 4 or more sentences in each paragraph. The teacher may offer advice on how to improve your paragraphs if needed. You must write using complete sentences. <u>You must write using complete sentences.</u>

Sentence Order:

- Sentence # 1: The first sentence should compare the cell part to the analogy. For example: mitochondria are like the engine of a car.
- Sentence # 2 and 3: The second and third sentence should describe the details of the cell part (structure). Write the definition of each of the cell parts in details using scientific terms.
- Sentence # 4: The fourth sentence should describe the comparison of the analogy. Only write about the analogy. For example: the engine of the car generates energy for the car.

Group/ Individual Work:

Students will have enough time in class to work with their partners. Paragraphs are due in class. Partners can discuss ideas, concepts, analogies and supporting evidence. Partners can turn in the same paragraph but each member must write it up individually at first.

Going Further:

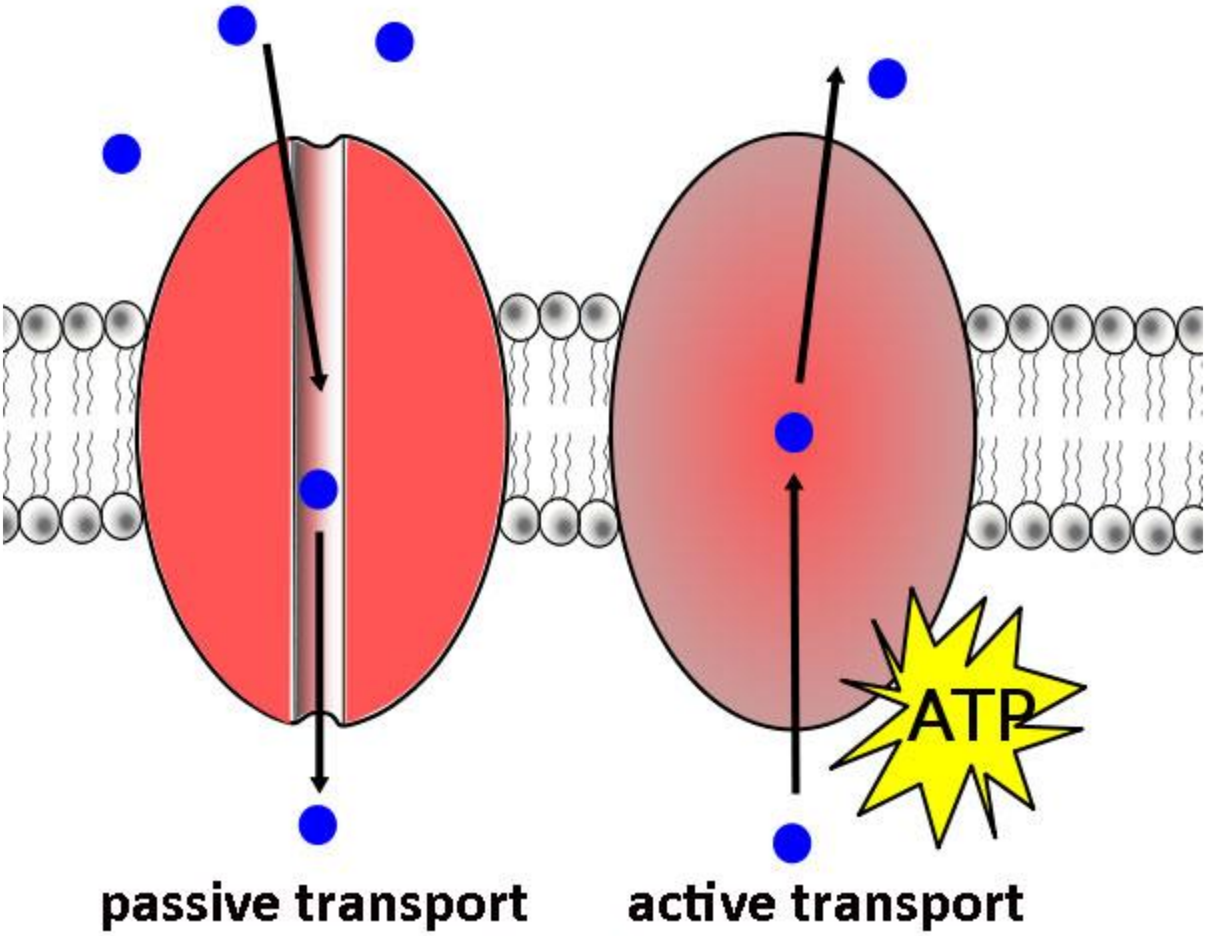
Class time will be only allotted for these 9 paragraphs following assigned time for research. There are two extra paragraphs that you are required to complete as homework or in class if you were fast and prepared. These two paragraphs are related to the two present in plant cells which are: chloroplast and cell wall.

Visual Aids:

Every cell part with its paragraph must have a picture associated with it.
Fill in the table before writing the paragraph in details.

	Organelle	Analogy
1.	Cell membrane	
2.	nucleus	
3.	nucleolus	
4.	mitochondria	
5.	ribosomes	
6.	Rough Endoplasmic Reticulum	
7.	Smooth Endoplasmic Reticulum	
8.	Golgi Apparatus	
9.	Lysosomes	

Red Rover Activity



Summary

Students compare and contrast passive and active transport by playing a game to model this phenomenon. Movement through cell membranes is also modeled, as well as the structure and movement typical of the fluid mosaic model of the cell membrane. Concentration gradient, sizes, shapes and polarity of molecules determine the method of movement through cell membranes.

Vocabulary/Definitions

Active transport: The movement of substances through the cell membrane that requires energy.

Passive transport: The movement of particles through the cell membrane that does not require energy.

Procedure

Background

Before starting the game, students review the activity sheet to familiarize themselves with the transport types and related topics. The teacher serves as the game facilitator, announcing the type of transport and summing up what has happened at the end of each session. During the activity, remind students about the concentration gradient and dynamic equilibrium.

Before the Activity

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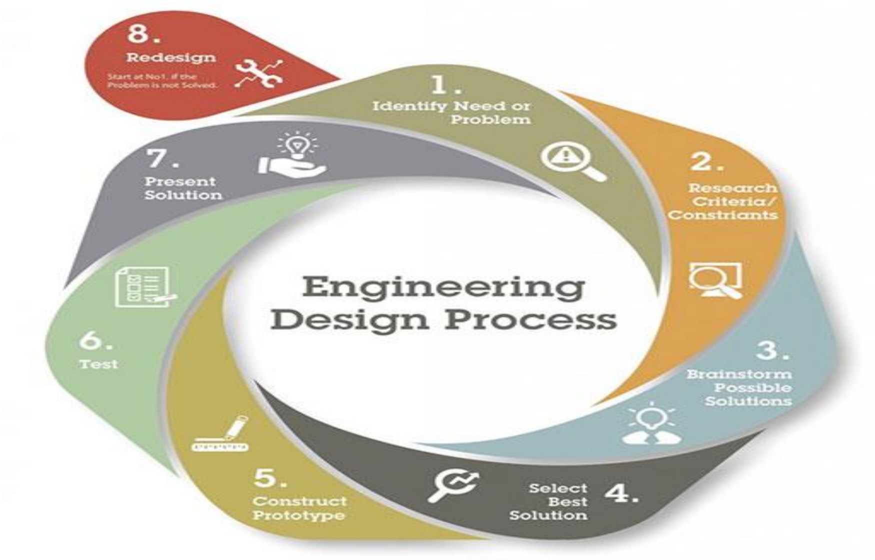
1. Print out the game cards that illustrate ions, molecules and cell membrane members. Hole-punch the cards on the top two corners and tie yarn through each to make placards for each student to wear during the activity, illustrating their roles. Use the pink atoms as potassium or another ion and write the ion element and charge on each. Have students write the charges on the sodium and chlorine atoms. (Tip: To make these cards re-usable, copy them onto card stock and laminate before punching the holes. Dry erase marker wipes off the laminated surface so the blank atoms can be easily changed.)
2. Move aside desks and tables to clear a space to conduct the game. Or arrange to go outside or to the gym.
3. Give students the activity sheet prior to the activity so they may familiarize themselves with the various types of transport being studied. Also have students review shape and structure of molecules to determine their polarity and method of movement into and out of the cell membranes.

With the Students

1. Offer students the stack of game cards, face down, and have them randomly choose their roles in the game by choosing a card. Have them place the placards around their necks so everyone knows their roles in the game.
2. Direct students who have drawn similar cards to group together to talk about their strategy for movement into the cell membrane. Suggest they look over the activity sheet to review what type of transport they are able to participate in each time. Likewise, have members of the lipid bilayer and the proteins discuss placement of their proteins within the membrane.
3. Begin the game by announcing which transport type will be illustrated. Similar to playing "Red Rover," the particles try to enter the cell and still be aware of the dynamic equilibrium that takes place in conjunction with the concentration gradient. Have the cell membrane hold hands so as to be "fluid" enough for small particles such as water, carbon dioxide and oxygen gas to enter and exit the cell at will, while charged particles must enter and exit the cell only through their specific channel proteins. Have the channel proteins announce which specific ion they allow to enter and exit. Have the carrier proteins also announce their specific molecule, such as glucose or amino acids.
4. Periodically stop to discuss what the students are modeling. Transition to new games by summarizing and discussing what happened. Restart new games, announcing different transport types. Periodically allow students to switch roles during the game so that they gain perspective for different parts of the process. Remind students about the concentration gradient and dynamic equilibrium.

Osmosis and Diffusion Design Challenge

Design a Setup that would demonstrate how ***atoms or molecules move into and out of the cell: Diffusion OR the movement of water molecules: Osmosis***. Make sure to follow the Engineering
Design Process.



When you *complete stage 4*, make sure to share your design with your teacher with the list of materials needed for approval.

Suggested Materials: You can pick and choose from the list:

- zip lock bags
- food coloring (blue & yellow)
- plastic grocery bags
- rubber bands
- iodine
- starch
- table salt
- dialysis tubing
- balances
- Plastic wrap
- Cardboards
- Aluminum foil
- droppers
- beakers
- tap water
- Masking tape
- Corn syrup
- markers

- paperclips
- Erlenmeyer flasks
- test tubes

Assignment:
Prepare a PowerPoint presentation that's that covers everything you have done from the beginning of the Design Process until the end. It should include the results of the design challenge in terms of osmosis or diffusion and the why behind it. Your presentation should be based in images on every step on the way with minimum text. Most of the explanation should be done verbally by the team members. Each presenter should be able to answer related questions and defend the project. <u>You may use your mobile phones to take pictures.</u> Your presentation file should be uploaded to the Presentations Folder on Google Drive.
<u>Deadline for file submission and presentation date will be announced on Moodle.</u>

CONTROL GROUP WORKSHEETS

Food coloring & Water Activity

Materials

- **Two 250 ml beakers filled with water**
- **blue Food coloring**
- **droppers**
- **hotplate**
- **Markers**

Question:

What do you think will happen if we add few drops of food coloring into cold water versus hot water? What is your hypothesis?

____

____

____

____

____

Use the following instructions to test your hypothesis:

7. Label your beakers 1 & 2
8. Add 100 ml of water to each beaker (1 & 2)
9. Place beaker 2 on the hotplate to heat it for around 5 minutes
10. Add 4 drops of food coloring to the water in beaker 1. Observe what happens.
11. Add 4 drops of food coloring to the water in beaker 2. Observe what happens.
12. Describe your observations in the spaces below.

Results:

D. Observations of beaker 1 (cold water & food coloring).

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E. Observations of beaker 2 (hot water & food coloring).

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Analysis:

C. Analyze and conclude. Justify your answers based on evidence from your observations in beakers 1 & 2.

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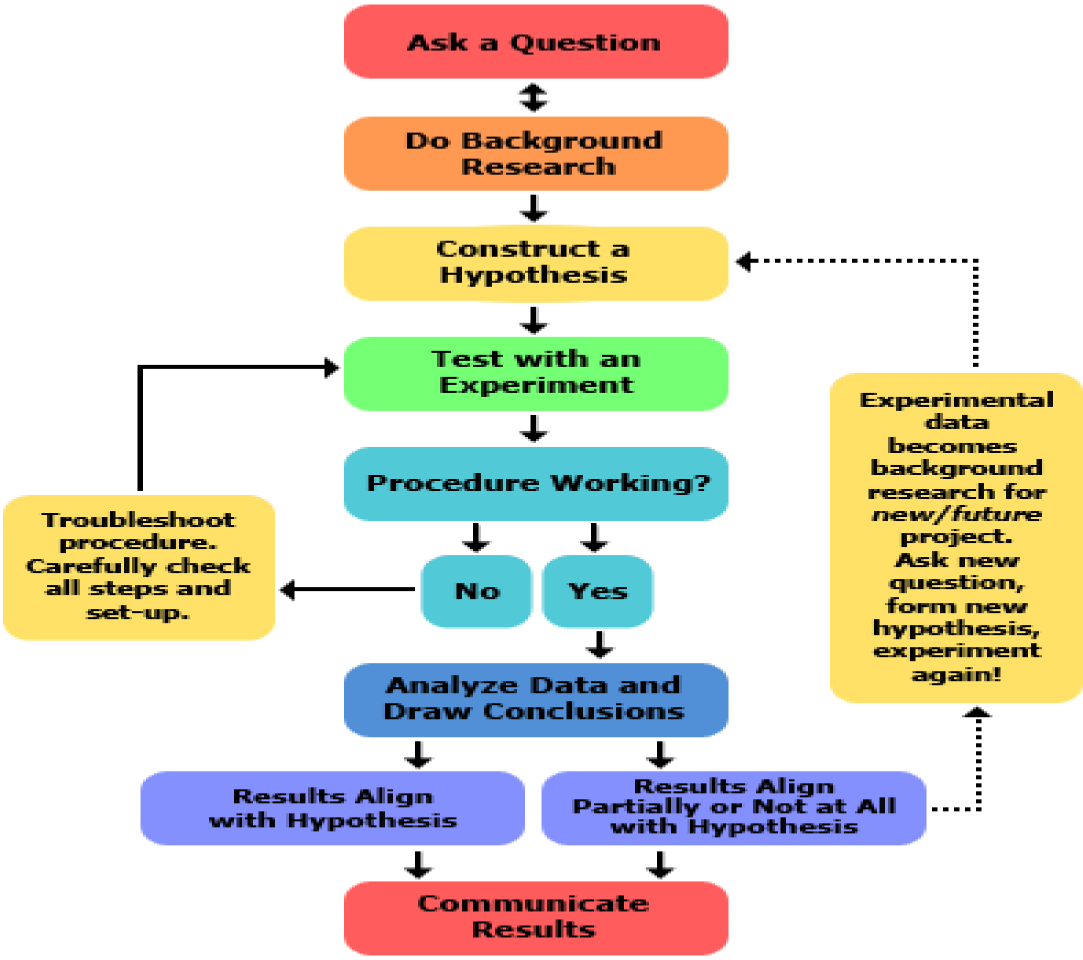
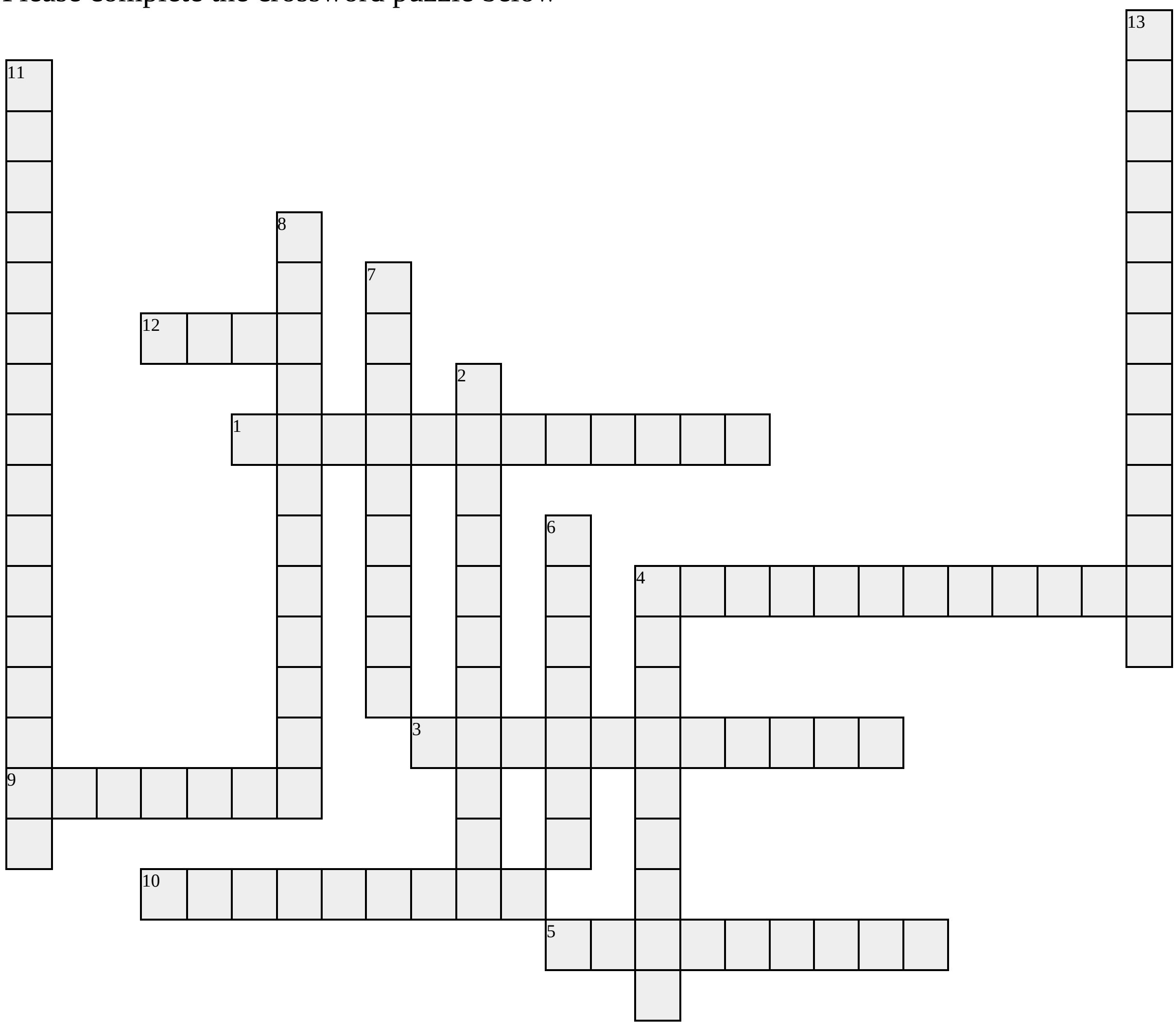


<u>Essential features of inquiry</u>

1. Learner Engages in Scientifically Oriented Questions
2. Learner Gives Priority to **Evidence** in Responding to Questions
3. Learner Formulates **Explanations** from **Evidence**
4. Learner Connects Explanations to Scientific Knowledge
5. Learner Communicates and Justifies **Explanations**

Please complete the crossword puzzle below



Across:

1. bean-shaped with inner membranes breaks down sugar molecules into energy

3. Trap energy from sun to make food for the plant by photosynthesis.

5. Small, round, with a membrane and breaks down larger food molecules into smaller molecules and digest them.

4. Complex network of tubules that is important for cell movement.

9. An oval shape that contains the genetic material and controls cell activities.

10. Present only in the plant cell for

Down:

2. A green pigment that is only presents in plant cells and give it its color.

4. A thick, jelly-like material found inside the cell membrane that supports and protects the cell organelles.

6. Vesicles present in the plant cell that stores food, water and wastes.

7. Involved in protein synthesis.

8. stack-like structures that are involved in packaging, sorting and modifying macromolecules (lipids and proteins) to be excreted or used within the cell .

11. Surrounds the nucleus and controls movement of materials in/out of

support and protection.

12. Smallest basic unit of all living things.

nucleus.

13. Controls movement of materials in/out of cell.

Cell Organelles Worksheet

Complete the following table by writing the name of the cell part or organelle in the right hand column that matches the structure/function in the left hand column. A cell organelle may be used more than once.

Structure/Function	Organelle
Stores material within the cell	
Closely stacked, flattened sacs (plants only)	
The sites of protein synthesis	
Transports materials within the cell	
The region inside the cell except for the nucleus	
Organelle that manages or controls all the cell functions in a eukaryotic cell	
Contains chlorophyll, a green pigment that traps energy from sunlight and gives plants their green color	
Digests excess or worn-out cell parts, food particles and invading viruses or bacteria	
Small bumps located on portions of the endoplasmic reticulum	
Provides temporary storage of food, enzymes and waste products	
Firm, protective structure that gives the cell its shape in plants.	
Produces a usable form of energy for the cell	
Packages proteins for transport out of the cell	
Everything inside the cell including the nucleus	
Site where ribosomes are made	
Provides rigidity for plant cells	
Provides support for the cell	
Consist of hollow tubes which provide support for the cell	
Outer membrane of the cells that controls the transport of materials.	

Put a check in the appropriate column(s) to indicate whether the following organelles are found in plant cells, animal cells or both.

Organelle	Plant Cells	Animal Cells
Cell Wall		
Chloroplast		
Cytoplasm		
Cytoskeleton		
Endoplasmic reticulum		
Golgi apparatus		
Lysosome		
Mitochondria		
Nucleolus		
Nucleus		
Plasma membrane		
Large vacuole		
Ribosome		
Small Vacuole		

Cell City Analogy

In a faraway city called Grant City, the main export and production product is the steel widget. Everyone in the town has something to do with steel widget making and the entire town is designed to build and export widgets. The town hall has the instructions for widget making, widgets come in all shapes and sizes and any citizen of Grant can get the instructions and begin making their own widgets. Widgets are generally produced in small shops around the city; these small shops can be built by the carpenters union (whose headquarters are in town hall).

After the widget is constructed, they are placed on special carts which can deliver the widget anywhere in the city. In order for a widget to be exported, the carts take the widget to the postal office, where the widgets are packaged and labeled for export. Sometimes widgets don't turn out right, and the "rejects" are sent to the scrap yard where they are broken down for parts or destroyed altogether. The town powers the widget shops and carts from a hydraulic dam that is in the city. The entire city is enclosed by a large wooden fence, only the postal trucks (and citizens with proper passports) are allowed outside the city.

Match the parts of the city with the parts of the cell.

1. Mitochondria:
2. Ribosomes:
3. Nucleus:
4. Endoplasmic Reticulum:
5. Golgi Apparatus:
6. Protein:
7. Lysosomes:
8. Cell membrane:
9. Nucleolus:

Cellular transport worksheet

1. What is a concentration gradient?

____

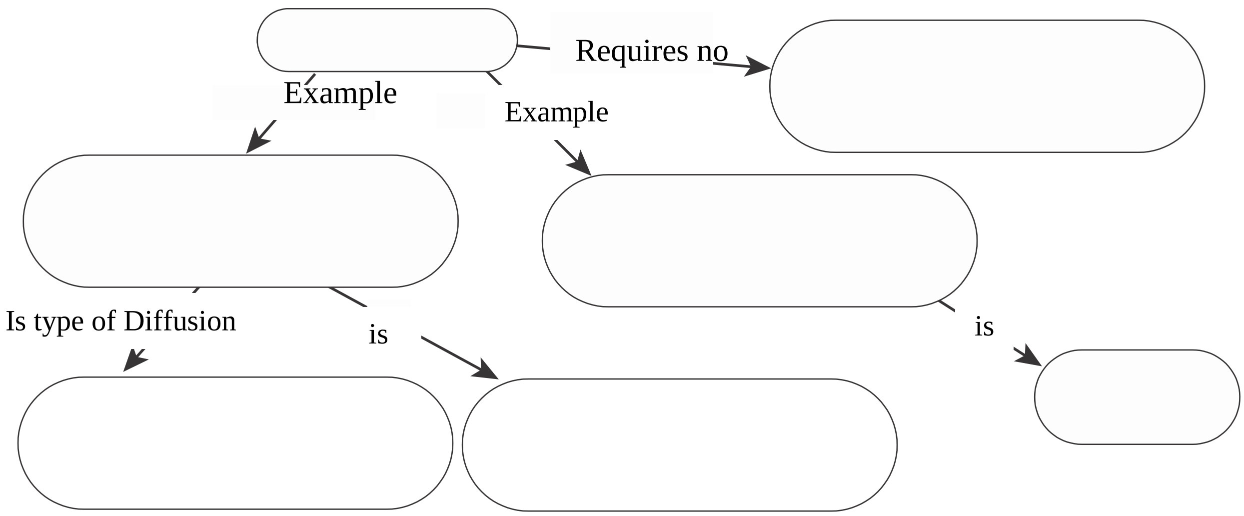
____

2. What does it mean for a molecule to diffuse down a concentration gradient?

____

____

3. Complete the concept map below about passive transport using the following words or phrases: Osmosis, energy, facilitated diffusion, the movement of molecules from high to low concentration, diffusion, passive transport, diffusion of water.



4. How does facilitated diffusion differ from simple diffusion?

____

____

5. What will happen to a houseplant if you water it with salt water (a hypertonic solution)?

____

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6. How is active transport different than simple diffusion and facilitated diffusion?

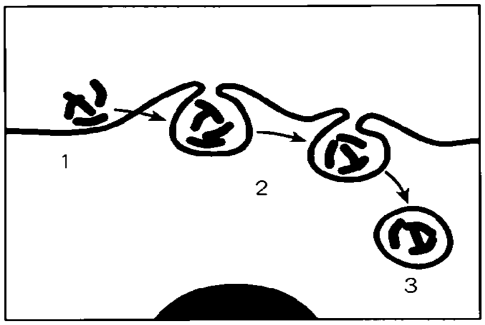
____

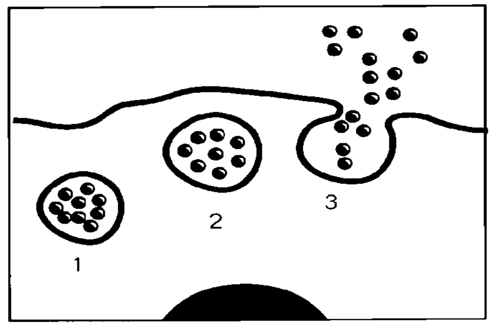
7. The prefix *exo*- means "out of" and the prefix *endo*- means "taking in". How do these meanings relate to the meaning of exocytosis and endocytosis?

____

____

8.





A B

What process is shown in Figure A? ______________________________

What process is shown in Figure B? ______________________________

9. What does it mean that biological membranes are selectively permeable?

____

____

10. What is osmosis?

____

____

11. When will water stop moving across a membrane?

____

____

12. Matching:

	Situation	Description
______	**12.** Two solutions are isotonic.	**a.** The solution is above strength in solute.
______	**13.** A solution is hypertonic.	**b.** The solutions are the same strength.
______	**14.** A solution is hypotonic.	**c.** The solution is below strength in solute.

13. What happens during the process of facilitated diffusion?

____

____

14. The energy-requiring process that moves molecules and ions across a cell membrane against a concentration difference is called____________________

Potato Lab Activity

Osmosis is the passive movement of water molecules from an area of high concentration of water to an area of low concentration of water through a semi-permeable membrane. It requires no energy (ATP). Osmosis takes place until equilibrium is reached.

Materials:

- Raw potatoes
- Digital balance
- Tap water
- Knife
- forceps
- Weighing paper
- 100 g of Salt
- Tap water
- 2 beakers

Procedure:

1. Fill one beaker with 400 ml of tap water and label it properly.
2. Mix 100 grams of salt with 400 ml of tap water and pour them into the second beaker. Make sure you label it properly too.
3. Obtain 2potato pieces from your teacher.
4. Use the balance to find the mass of the first piece (Record the mass in your data table).
5. Place the first piece of potato in the first container (Tap water). Make sure it is all covered. You can cut it into sizes that can be totally submerged.
6. Use the balance to find the mass of the second piece (Record the mass in your data table).
7. Place the second piece of potato in the second container (Salty water).Make sure it is all covered. You can cut it into sizes that can be totally submerged.
8. Observe the potato piece at different intervals within the two days' time and record your observations in your data sheet. After two days, remove the first potato with forceps and dry it gently on a paper towel.
9. Find its mass and record it in your data table.
10. Repeat steps 9 and 10 for the second piece of potato.

Table showing the initial and final masses of the pieces of potato placed in tap water vs salty water				
		Initial Mass in grams	**Final Mass in grams**	**Change in Mass (grams)**
Container 1	**Tap water**			
Container 2	**Salty water**			

Q and A:

1. Explain the difference between what happened to the potato pieces in fresh water and in salty water.
2. Calculate the mass of water that moved:
   a. into the potato:
   b. out of the potato:
3. Explain in details ***What*** happened and ***Why*** in each of the cases above.

Passive transport and Bag Experiment

OBJECTIVES

- Predict net movement of molecules across a semi-permeable membrane
- Indicate which molecules move during diffusion and osmosis
- Determine changes in volume caused by osmosis
- Determine change in mass caused by diffusion
- Define hypertonic, hypotonic and isotonic solutions

WHAT YOU NEED

- Starch solution
- Digital balance
- Iodine solution
- Small plastic zip lock bag
- Rubber bands
- 250ml Beaker
- 100ml measuring cylinder

WHAT TO DO

1. Add 30 ml of starch solution to the plastic bag and zip it well.
2. Measure100ml of water and pour into 250ml beaker.
3. Add10 drops of iodine to water in the 250 ml beaker.
4. Place the plastic bag in the 250ml beakers that the starch solution is submerged in the iodine water mixture
5. Record your observations at the beginning of the experiment and after 15minutes.
6. Record your observations in the **table below**.

QUESTIONS

While waiting for15minutes answer the following questions:

1. What is the main difference between osmosis and diffusion

2. Molecules tend to move from areas of high concentration to areas of low concentration. At the start of the experiment:

a. Is the bag or beaker more concentrated in starch?
b. Is the bag or beaker more concentrated in iodine?
c. Iodine solution: Is the bag or beaker hypertonic
d. Starch solution: is the bag or beaker hypertonic?

	Solution in the Beaker	Solution in the bag
Starting color		
Colorafter15minutes		
Initial amount of water in beaker		
Amount of water in beaker after15minutes		
Initial mass of the plastic bag with its contents (before submerging it in the beaker)		
Final mass of the plastic bag with its contents (after 15 minutes)		

1. Based on your observations, which substance moved, the iodine or the starch?
2. How did you determine this?
3. The plastic bag was permeable to which substance?
4. Is the plastic bag selectively permeable? Explain.
5. What happened to the amount of water in the beaker? Why did this happen?
6. Sketch the beaker and bag. Use arrows to illustrate how diffusion occurred.
7. What would happen if you did the experiment again with the starch in the solution and the iodine in the bag
8. Why is it not a good idea to store iodine in a plastic bag?

Assignment:

Prepare a three minutes PowerPoint presentation with your partner about your experiment results explaining ***in visuals and labeling only*** what has happened and why and be ready to answer related questions. No text on the slides other than labeling.

APPENDIX D

CONCEPT TEST 1

Cellular Structure and Function

INSTRUCTIONS

- Read the questions carefully
- Circle the correct answer and the correct reason that best fits your choice.
- Write the letters of your choices (answer and reason) to the left side of the questions.
- You can only choose one answer for all questions.

1. What is a cell?

    A. Building blocks of living and non-living things.
    B. A structural and functional unit of life that contains hereditary information DNA.
    C. The smallest unit of living and non-living things.

1.1. Reason:

1. All cells are composed of nutrients that enter the cells from outside.
2. All organisms including animals, plants and microorganisms are made up of cells.
3. Most cells are so small that their details can only be seen with a microscope.
4. Cells are the non-living building blocks of the body

2. All matter, including cells, is made of atoms

    A. true
    B. false

2.2. Reason:

1. Atoms and cells are made up of a smaller part called nucleus.
2. Living organisms are made up of cells rather than atoms.
3. Cells are made of molecules, molecules are made of atoms and atoms are the building blocks of matter.
4. Cells and atoms are the same size.

3. Which of the following clues would tell you whether a cell is prokaryotic or eukaryotic?

    A. The presence or absence of a cell wall.
    B. Whether or not the cell has organelles that have membranes around them.
    C. The presence or absence of mitochondria.

3.3. Reason:

1. Whether or not the cell produces energy.
2. Whether or not the cell contains DNA.
3. Prokaryotic cells lack any organelles that have membranes around them.
4. Whether or not the cell produces its own food.

4. The role of nucleus in cells:

A. Absorb water from surrounding air.
B. Gives off oxygen and take in carbon dioxide.
C. Controls and regulates the activities inside the cell.

4.4. Reason:

1. Nucleus center holds all the instructions needed to get in nutrients for cells and release wastes.
2. Nucleus controls the production of energy in the cells.
3. Nucleus contains the cell's hereditary information (DNA) and controls the cell's growth and reproduction.
4. Nucleus carries out materials in and out of the cell.

5. Plant cells differ from animal cells in that plant cells:

A. Have cell wall and chloroplasts.
B. Have organelles surrounded by membranes.
C. Are smaller than animal cells.

5.5. Reason:

1. Plant cells have a nucleus that contains DNA.
2. Plant cells trap sunlight to make up their own food.
3. Plant cells divide unlike animal cells.
4. Plant cells are soft unlike animal cells.

Answer key

1. **B**
1.1. **2**
2. **A**
2.2. **3**
3. **B**
3.3. **3**
4. **C**
4.4. **3**
5. **A**
5.5. **2**

CONCEPT TEST 2

Osmosis and Diffusion

Instructions:

- Answer all the questions on this paper
- Each question has 2 parts: a multiple choice and a reason
- Please. **<u>Circle one answer from both the answer and reason sections</u>** of each question. Write also the letters of selected choices on the left hand side of every question.

1a.Suppose there is a large beaker full of pure water and a drop of blue food coloring is added to the beaker of water. Eventually the water will turn a light blue color. The process responsible for blue dye becoming evenly spread throughout the water is:

a. Osmosis
b. Diffusion
c. Reaction between water and food coloring

1b. **the reason for my answer is because:**

a. The absence of a membrane means that diffusion and osmosis cannot occur.
b. There is a movement of food coloring particles between regions of different concentrations.
c. The blue food coloring separates into small particles and mixes with water.
d. The water molecules move from one region to another.

2a. during the process of diffusion, particles will generally move from:

a. High to low concentrations
b. Low to high concentrations

2b. **the reason for my answer is because:**

a. There are a low amount of particles in one area; they move to a crowded area with less space.
b. Particles in areas of greater concentration are more likely to move to other areas of lower concentration.
c. The particles tend to move until the two areas will have equal number of particles and then the particles will stop moving.
d. There is a greater chance that particles repel each other.

3a. as the difference in concentration between two areas increases, the rate of diffusion:

a. Decreases
b. Increases

3b. **the reason for my answer is because:**

a. There is less space for the particles to move.
b. If the concentration is high enough, the particles will spread less and the rate will be slowed.
c. The molecules want to spread out by repelling each other.
d. There is a greater possibility of random motion of particles to other regions.

4a. a glucose solution can be made more concentrated by:

a. Adding more water
b. Adding more glucose

4b. **the reason for my answer is because:**

a. The more water there it, the more glucose will it take to dissolve in the solution.
b. Concentration means the dissolving of anything liquid and solid.
c. For a solution to be more concentrated one must increase the number of dissolved particles.
d. For a solution to be more concentrated one must add more liquid.

5a. Suppose you add a drop of blue food coloring to a container of clear water and after several hours the entire container turns light blue. At this time the molecules of food coloring:

a. Have stopped moving.
b. Continue to move randomly.

5b**. the reason for my answer is because:**

a. The entire container is the same color; if the food coloring molecules were still moving, the container would be different shades of blue.

b. If the food coloring molecules stopped, they would settle to the bottom of the container.

c. Molecules are always moving; however, the food coloring and water molecules will be eventually moving randomly instead of moving from a region of high concentration to low concentration.

d. The food coloring is a liquid; if it were solid the molecules would stop moving.

6 a. Suppose there are two large beakers with equal amounts of clear water at two different temperatures. Next, a drop of green food coloring is added to each beaker of water. Beaker 1 is placed at 25^{o}C whereas beaker 2 is at 35^{o}C. Eventually the water turns light green (see Figure 1 below). Which beaker became light green **first**?

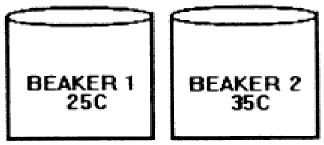


Figure 1

a. Beaker 1
b. Beaker 2

6 b**. the reason for my answer is:**
a. The lower temperature breaks down the food coloring molecules.
b. The food coloring molecules move faster at higher temperatures.
c. The cold temperature speeds up the molecules.
d. The low temperature helps the molecules to expand.

7a. In Figure 2 below, two columns of water are separated by a membrane through which only water can pass. Side 1 contains food coloring (dye) and water; Side 2 contains pure water. After two hours, the water level in Side 1 will be:

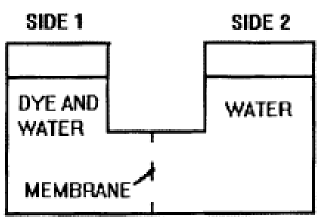


Figure 2

a. Higher
b. Lower
c. The same height

7b. **the reason for my answer is**:
a. Water will move from the region where is more food coloring particles to the region where there is less food coloring particles.
b. The concentration of water molecules is higher on Side 2 so water will move from side 2 to side 1.
c. Water will not move.
d. Water moves from the region where there is low concentration of water to high concentration.

8 a. Figure 4 below is a picture of a plant cell that lives in fresh water. If this cell was placed in a beaker of 25% salt water solution, the central vacuole would:

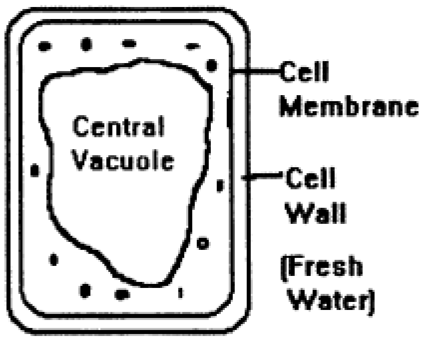


Figure 4

a. Increase in size.
b. Decrease in size.
c. Remain the same size.

8b. **the reason for my answer is:**

a. Salt absorbs the water from the central vacuole.
b. Water will move from the vacuole to the salt water solution.
c. The salt will enter the vacuole.
d. Salt solution outside the cell cannot affect the vacuole inside the cell.

9a. Suppose you killed the plant cell in <u>Figure 4 above</u> with poison and placed the dead cell in a 25% salt water solution. Osmosis would:
a. Not occur
b. Continue

9b. **the reason for my answer is:**
a. The cell would stop functioning so all processes will not occur.
b. .Osmosis is not random and requires cell energy.
c. Osmosis is random and does not require cell energy.
d. Osmosis is random and requires cell energy.

10a. all cell membranes are:
a. Semipermeable
b. Permeable

10b. **The reason for my answer is:**
a. They allow some substances to enter and leave the cell.
b. They allow some substances to enter, but they prevent any substance from leaving.
c. The membrane requires nutrients to live.
d. They allow ALL nutrients to pass.

Answer key:

1a. b

1b. b

2a. a

2b. b

3a. b

3b. d

4a. b

4b. c

5a. b

5b.c

6a. b

6b. b

7a. a

7b.b

8a. b

8b. b

9a. b

9b. c

10a. a

10b. a

APPENDIX E

ACHIEVEMENT TEST 1

CELLULAR STRUCTURE AND FUNCTION

INSTRUCTIONS

This test is composed of four main parts. In the first part, you have to answer 6 given statements by true or false. Part B includes 11 multiple choice questions where you have to select <u>one correct answer.</u> Part C involves short-answer questions where you have to use your skills to label and analyze different types of cells. Your ability to relate between cellular structure, function and real-life applications is tested in part D.

PART A: True or False Questions

<u>Answer the following statements as True or False and correct the false statements.</u>

Write your answers in the blanks below and correct the statements if needed in the available space below.

<u>Question I:</u>

a) In a eukaryotic cell, the nucleus is usually referred to as the command center because it contains the genetic material that controls the activities of the cell. (True/False)

____

b) The Golgi bodies are responsible for sorting and packaging proteins. (True/False)

____

c) An organ is defined as a differentiated structure within a cell that performs a specific function. (True/False)

____

d) Plant cells are characterized by the fact that they have a cell wall that provides rigidity. (True/False)

____

e) Lysosomes are vesicles present in plant cells that store water and nutrients. (True/False)

____

f) The amount of trapped sunlight energy increase as the number of chloroplasts increase inside a plant cell. (True/False)

____

PART B: Multiple choice Questions

<u>Question II:</u> Circle the correct answer and write the letter on the left side of the question.

1. Suppose you thoroughly and adequately examined a particular type of cell, using the transmission electronic microscope, and discovered that it completely lacked ribosomes. You would then conclude that this cell also lacked:

a) A nucleus
b) Water
c) Cellulose
d) Protein synthesis
e) Lipid synthesis

2. If a cell is to be compared to a city then the Endoplasmic Reticulum (ER) would be analogous to:

a) Power plant of the city
b) Security Gate of the city
c) Factory in the city
d) Delivery van
e) Road system

3. Alcohol consumption adversely affects the digestion of proteins within the liver cells, which can eventually lead to liver damage. Given this information, which organelle in the liver cells is most directly affected:

a) Nucleus
b) Golgi Apparatus
c) Rough ER
d) Lysosomes
e) Smooth ER

4. A cell biologist treats a cell so that the cell stops synthesizing lipids (fats). Which organelle will directly be affected?

a) Nucleus
b) Golgi Apparatus
c) Rough ER
d) Lysosomes
e) Smooth ER

5. If a cell decreases in size, then the demand of nutrients will______ and the supply of wastes will _______. The correct terms respectively are:

a) increase, increase
b) decrease, decrease
c) decrease, increase
d) increase, stay the same
e) decrease, stay the same

6. Which of the following does not apply to a cell:

a) all cells have genetic material
b) all cells are living
c) cells reproduce
d) cells are fundamental structures for plants and animals
e) all cells have membrane-bound organelles

7. To enter and leave the cell, substances must pass through:

a) Smooth ER
b) cell membrane
c) Golgi apparatus
d) nucleus
e) mitochondria

8. Which two organelles function as storage units; one for chemicals such as digestive enzymes and the other for such things such as: food, water and wastes respectively?

a) cytoplasm and vacuoles
b) vacuoles and cytoplasm
c) ribosomes and lysosomes
d) lysosomes and vacuoles
e) vacuoles and ribosomes

9. Which cell structures are similar in the way they protect, support, and hold the other organelles together?

a) Cell Wall, cytoplasm, and lysosomes
b) Cell membrane, cytoplasm and ribosomes
c) Cell wall, cell membrane and cytoplasm
d) Cell membrane, chloroplast and nucleus
e) Cell wall, chloroplast and nucleus

10. The fluid substance that holds the organelles of the cells is called:

a) Cytoplasm
b) Cell wall
c) Nucleus
d) Ribosome
e) Golgi body

11. The nucleolus is a prominent spherical body in the nucleus. Its function is:

a) DNA synthesis
b) Synthesis of ribosomes
c) Protein synthesis
d) Lipid Synthesis
e) Synthesis of enzymes

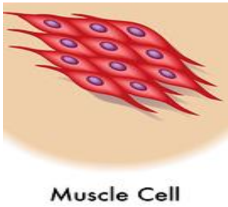
PART C: Short- Answer Questions

Question III: Refer to the figures below and answer the following questions

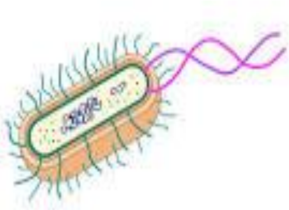
a. Which of the following cells are specialized cells? List all that may apply

b. Which of the following cells is a unicellular organism? List all that may apply.

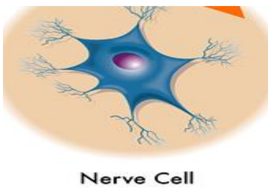
c. Which of the following cells is considered prokaryotic? List all that may apply.



A



B



C

Sperm Cell

D

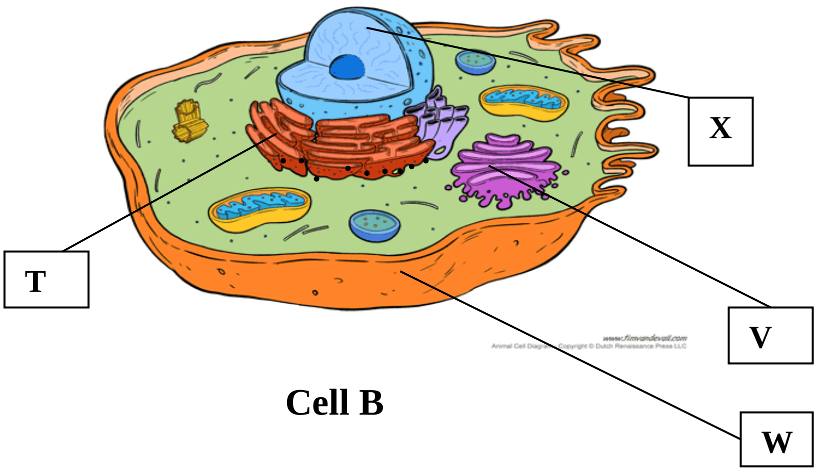
E

Red Blood Cells

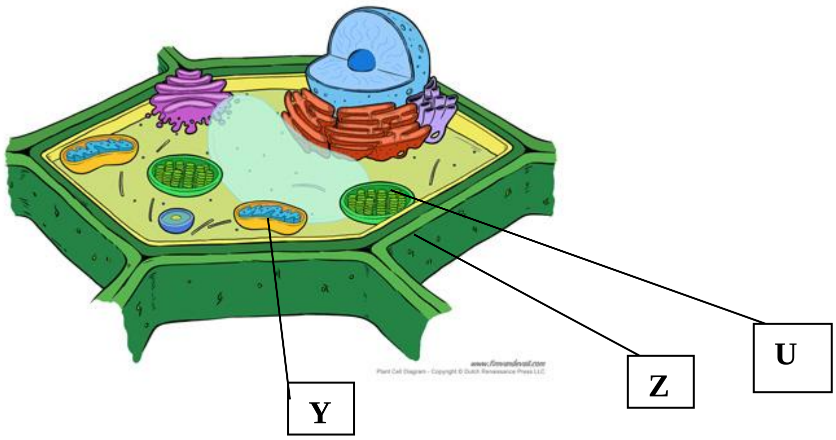
Question IV:

Use the following two diagrams to answer the questions below:

Cell A



Cell B



a. Label parts T, U, V, W, X, Y and Z in diagrams A & B.

T: ________________

U: ________________

V: ________________

W: ________________

Z: ________________

Y: ________________

Z: ________________

b. One of the cells above (A or B) died shortly and was left in the dark for some time. Which cell organelle was directly affected? Explain your answer.

c. Does Cell B have a cell membrane? Why or why not?

d. Are the above cells considered Prokaryotic or Eukaryotic? Justify your answer.

e. What is the difference between rough ER and smooth ER in terms of **structure and function**? Justify your answer.

PART D: Cellular structure & real life applications

Question V:

Your mom bought a fresh and crispy lettuce with some carrots from the grocery next home to prepare you a delicious bowl of salad for lunch. She then stored them in a basket on the balcony. When she came the next day to prepare the salad, she realized that the lettuce wilted and the carrot became limp.

a. What do you think has happened inside the cells of these vegetables that have caused them to wilt? Explain your answer by relating to the affected organelle.

b. List two external factors that you think may have contributed to the wilting of the vegetables.

c. What would you recommend your mom to do differently in order to prolong the freshness of these vegetables? Provide one recommendation and justify your answer.

Answer Key

PART A: True or False Questions: (out of 6)

a) True
b) True
c) False. An organelle is defined as a differentiated structure within a cell that performs a specific function.
d) True
e) False. Vacuoles are vesicles present in plant cells that store water and nutrients.
f) True

PART B: Multiple Choice Question:

Question II (out of 11)

1. D
2. E
3. D
4. E
5. B
6. E
7. B
8. D
9. C
10. A
11. B

PART C: Short-Answer Questions:

Question III (out of 3)

a. A, C,D,E
b. B
c. B

Question IV (out of 10)

a. (3.5 points: 0.5 each)

T: Ribosomes
U: Chloroplast
V: Cytoplasm
W: Cell membranes
X: Nucleus
Y: Mitochondria
Z: Cell Wall

b. Cell B. The organelle that was directly affected is the chloroplast since its function is to capture sunlight and convert it into glucose (photosynthesis). (1.5 points)
c. Yes, because all cells have a cell membrane to control what's entering or leaving the cell. (1.5 points)
d. They are Eukaryotic cells because they have membrane-bound structure, and these cells shown in the picture are plant and animal cell. (1.5 points)
e. The smooth ER doesn't have ribosomes attached and their function is to produce lipids while rough ER has ribosomes attached and they transport proteins. (2 points)

PART D: Cellular Structure & real life applications:

Question V (out of 4)

a. The affected organelle is the vacuole since the heat made the water stored in the vacuole to evaporate that's why it wilted.

b. - Heat from sunlight
   - Humidity from air

c. Place the lettuce in the fridge or put it in a bowl of cold water to prevent the water inside the vacuole from evaporating.

ACHIEVEMENT TEST 2

CELLULAR TRANSPORT

INSTRUCTIONS

This test is composed of four main parts. In the first part, you have to answer true or false for the 6 given statements. The second part contains 13 multiple choice questions where you have to select one correct answer. Part C involves short-answer questions where you have to use your skills to label and analyze different types of cellular transport. Your ability to relate between cellular transport and real-life applications is tested in part D.

PART A: True or False Questions

Answer the following statements as True or False and correct the false statements.

Write your answers in the blanks below and correct the statements if needed in the available space below.

Question I:

a) Endocytosis is a passive form of transport because it requires proteins for the passage of molecules across the membrane. (True/ False)___________

b) Simple diffusion is an active form of transport where molecules cross the membrane in the presence of energy. (True/False) __________

c) Diffusion continues until equilibrium is reached. (True/False) __________

d) The fluid mosaic model of a cell membrane is composed of phospholipids monolayer embedded with proteins. (True/False) __________

e) The cell membrane is considered as selectively permeable because its only allows specific substances to enter and exit the cell.(True/False) ___________

PART B: Multiple choice Questions

***Question II*: Circle the correct answer and write the letter on the left side of the question.**

1. Which of the following is an example of osmosis?

A. Intestinal cells use osmosis to absorb nutrients from food.
B. The human body uses osmosis to move proteins out of cells.
C. A single celled organism uses osmosis to take in food particles.
D. A plant's roots use osmosis to absorb water from soil.
E. The human cells use osmosis to transport proteins outside the cell.

2. How does particle size affect a molecules transport across the membrane?

A. It is easier for large molecules to diffuse across the cell membrane.
B. Particle size does not affect a molecule's transport speed across the cell membrane.
C. Particle size is less important than particle shape for calculating transport speed.
D. It is easier for small molecules to diffuse across the cell membrane.
E. Particles of only a specific shape cross the cell membrane.

3. Certain white blood cells called macrophages remove bacteria and worn out red blood cells by a process called:

A. Facilitated diffusion.
B. Phagocytosis.
C. Exocytosis.
D. Osmosis.
E. Simple diffusion

4. The main differences between active and passive transport are:

A. Active transport works against gravity (for example, upwards from the roots of a tree); passive transport works with gravity.
B. Passive transport occurs primarily in single-cell organisms; active transport occurs primarily in multi-cellular organisms.
C. Active transport requires cellular energy for substances to cross the cell membrane; passive transport does not require cellular energy.
D. Passive transport does not require any cellular proteins; active transport requires cellular proteins.
E. Passive transport allows the passage of large molecules; active transport allows the passage of small molecules.

5. The exchange of gases such as oxygen and carbon dioxide between blood and cells occurs through:

A. Facilitated diffusion.
B. Simple diffusion.
C. Endocytosis.
D. Osmosis.
E. Exocytosis.

6. Which of the following is TRUE about Active Transport?

A. Substances can only move into cells, not out of cells.
B. Substances do not require additional energy to move in and out of cells.
C. Substances can move from areas of low concentration to areas of high concentration.
D. Substances can only move across the membrane if they are water soluble.
E. Substances can only move across the membrane if they are lipid soluble.

7. In facilitated diffusion, the special channels that help the substances cross the cell are made up of:

A. Lipids.
B. Water.
C. Nucleic acids.
D. Proteins.
E. Vitamins.

8. Which of the following molecules are both transported out of the cells through exocytosis:
A. proteins such as enzymes and hormones
B. Sodium and potassium ions.
C. Carbon dioxide and oxygen gas.
D. Water and glucose.
E. Vitamins and bacteria.

9. Which of the following comparisons are NOT Correct?

A. Endocytosis- entering by a vesicle.
B. Exocytosis- leaving by a vesicle.
C. Active transport-against or up the gradient.
D. Facilitated diffusion- with or down the gradient.
E. Hypotonic solution- cells shrink.

10. Upon observation of a cell using an electron microscope, scientists noted a large number of mitochondria near the plasma membrane within the cell. The scientist will probably hypothesize that the cell used energy for:

A. Diffusion.
B. Osmosis.
C. Facilitated diffusion.
D. Phagocytosis.
E. Active transport.

11. Why are protein channels involved in active transport often called pumps?

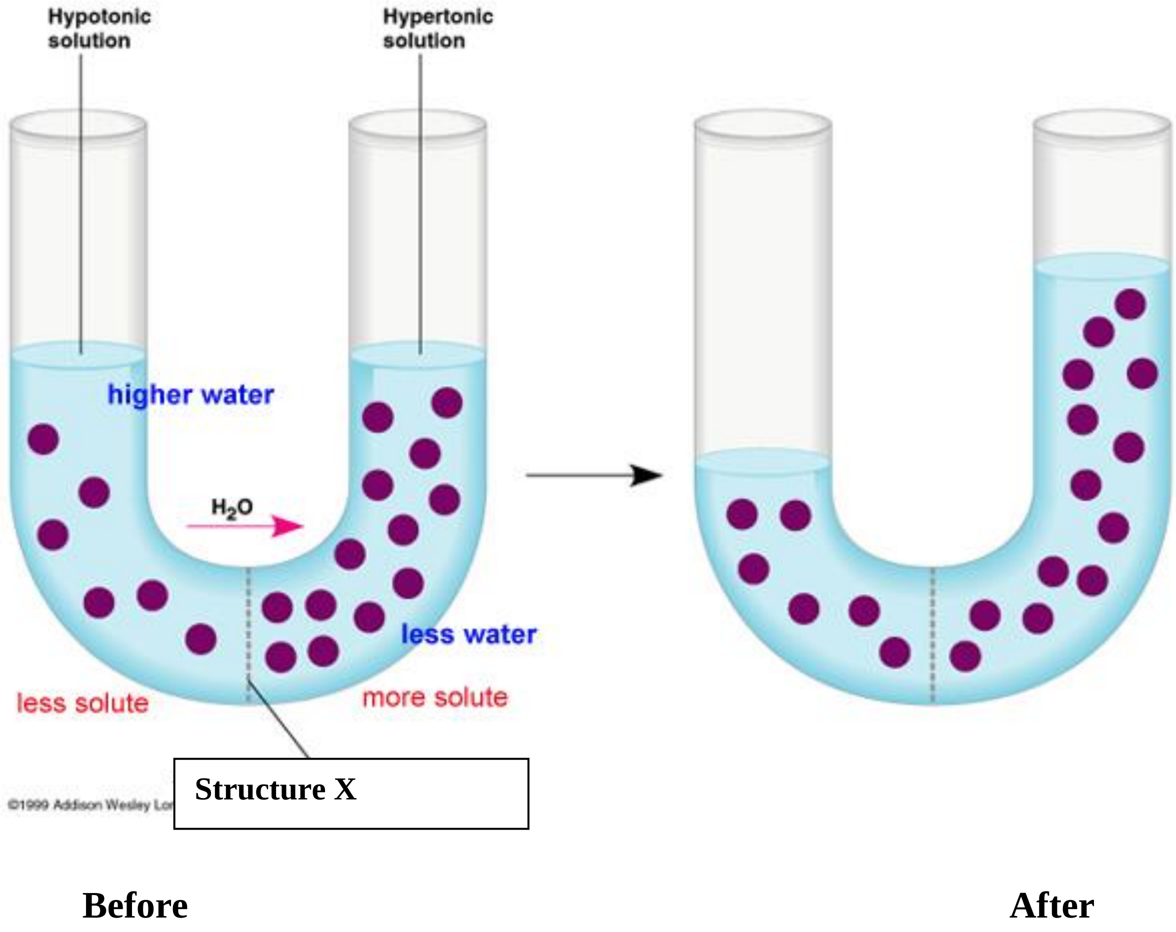
A. They use energy to move substances up the concentration gradient.
B. They use energy to move substances down the concentration gradient.
C. They use energy to bind the substance to the protein.
D. They use energy to release the substance from the protein.
E. They cause the plasma membrane to behave like a pump that pulls up water against the force of gravity.

12. Which of the following is TRUE about homeostatic mechanisms (homeostasis)?
A. Keep variables at a specific point.
B. Help to keep a relatively balanced environment in the body.
C. Act to keep the variables out of the normal range.
D. Produce most diseases.
E. Is not essential for normal body functioning.

13. Which of the following is the useful form of energy for the cell?
A. Adenosine Diphosphate (ADP)
B. Adenosine Triphosphate (ATP)
C. Heat Energy
D. Kinetic Energy
E. Glucose

PART C: SHORT ANSWER QUESTIONS

Question III:



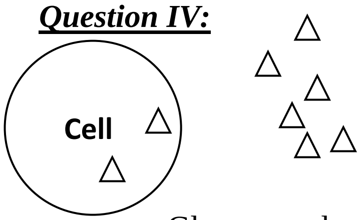
Use the diagram above to answer the following questions in the space:

a) Structure X plays the same function as one of the cell structures. Name this cell structure.

b) Explain why is the level of water higher on the right side than on the left side after the transport process has taken place.

c) Name the process of transport indicated in the above diagram.

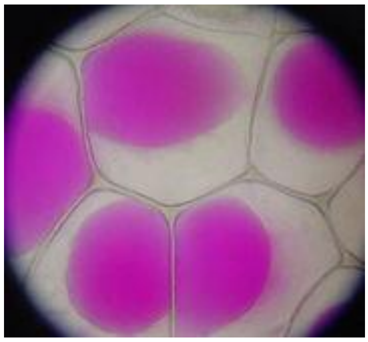
Question IV:



△ _______ Glucose molecule

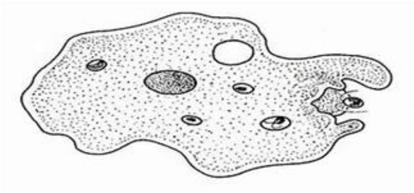
After digestion glucose enters the muscle cells.

A



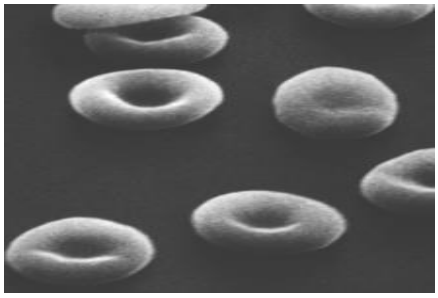
Plant cells after not being watered lately

.**B**



An Amoeba engulfing a particle of food.

C

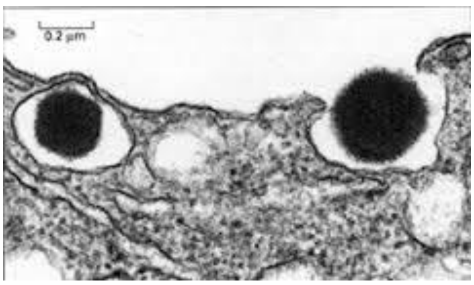


Red Blood cells placed in water.

D

Ink in water

F



Amoeba expelling wastes.

E

1. Which of the above diagram(s) above represent an example of each of the following?

List all that may apply.

a. endocytosis

b. facilitated diffusion

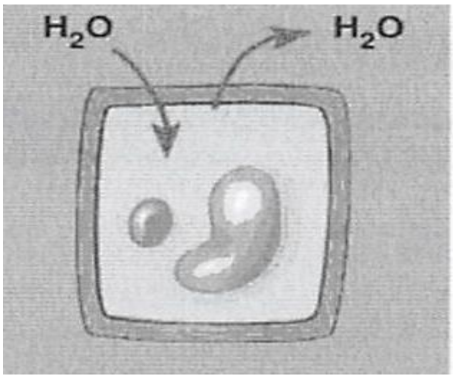
c. exocytosis

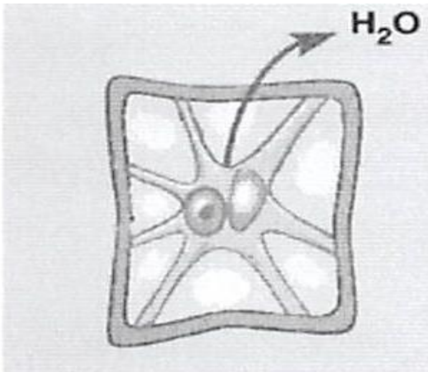
d. osmosis

e. active transport

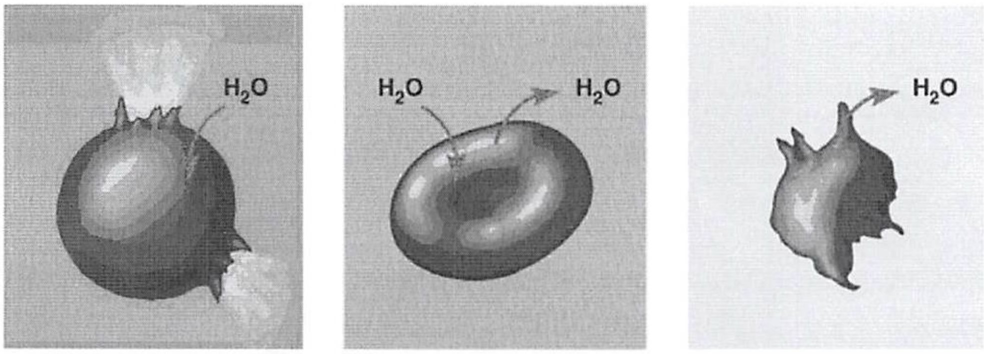
Plant cells

2.





Red Blood Cells



a. Based on the movement of water as indicated by arrows. Label each cell in the boxes above as isotonic, hypertonic and hypotonic.

b. Explain why the plant cells do not burst while the red blood cells do when placed in the same type of solution above.

PART D: Real-life Applications

<u>Question V:</u>

A: 30% water in soil

B: 20% water in soil

a) Explain why plant B wilted while plant A did not after a certain period of time.

b) Explain what would you do to make plant B become fresh and rigid? Justify your answer.

c) Label each of the above plant's soil (A & B) as hypotonic or hypertonic in the boxes above. Justify your answer in the space below for each diagram.

Answer Key

PART A: True or False Questions: (out of 5)

a. False. Facilitated Diffusion is a passive form of transport because it requires proteins for the passage of molecules across the membrane.

b. False. Endocytosis is an active form of transport where molecules cross the membrane in the presence of energy.

c. True.

d. The fluid mosaic model of a cell membrane is composed of phospholipids bilayer embedded with protein.

e. True.

PART B: Multiple Choice Questions:

Question II (out of 13)

1. D
2. D
3. B
4. C
5. B
6. C
7. D
8. A
9. E
10. E
11. A
12. B
13. B

PART C: Short-Answer Questions:

Question III (out of 3.5)

a) Semi-permeable membrane (1 point)

b) Since there is higher concentration of water and lower concentration of solutes on the left side, the water moves to the right side to reach equilibrium (1.5 points)

c) Osmosis (1 point)

Question IV (Out of 3.5/ 0.5 each)

a. C

b. A

c. E

d. B and D

e. C and E

(Out of 3.5)

2. a. Plant Cells: Isotonic, Hypertonic **(2.5 points)**
Red Blood Cells: Hypotonic, Isotonic and Hypertonic.

b. Because the plant cells have a cell wall that supports the cell and provides rigidity while red blood cells don't **(1 point)**

PART D: real life applications:

Question V (out of 5)

a. Plant A has more water in the soil (hypotonic) than the roots and stem (hypertonic). Therefore, water will move by osmosis up to the roots, stem and leaves which make it stay longer

OR

Water will diffuse into the cells of the plant filling the vacuole which will hence prevent the plant from wilting and keeps the plant cells swollen**. (Any of these answers is right/1.5 points)**

b. Add more water to make the soil of plant B (hypotonic) in order for water to move up to the leaves **(1.5 points)**

c. Plant A has a higher concentration of water (30%) and less solute than plant B (20%). This implies that the soil of plant A is hypotonic while the soil of plant B is hypertonic **(2 points)**

APPENDIX F
LESSON OBJECTIVES 1
CELLULAR STRUCTURE AND FUNCTION

1. Describe the basic structures and functions of cells.
2. Describe structures or behaviors that help organisms survive in their environment (Obtaining nutrients, reproduction and supply of wastes).
3. Differentiate between a specialized cell and a unicellular organism.
4. List the two major categories of cells. Explain the difference and give examples.
5. Define an organelle.
6. Explain the function of each of the following structures: nucleus, nucleolus, nuclear membrane, cytoplasm, ribosome, lysosome, vacuole, smooth endoplasmic reticulum, rough endoplasmic reticulum, Golgi body, mitochondrion, chloroplast, cell membrane and cell wall.
7. Compare and contrast a plant cell and an animal cell.
8. Label an animal cell and a plant cell.
9. Differentiate between the structure of smooth endoplasmic reticulum and rough endoplasmic reticulum.

LESSON OBJECTIVES 2

CELLULAR TRANSPORT

1. Explain the structure of the cell membrane.
2. State the difference between active and passive transport across the membrane.
3. List the types of active transport.
4. List the types of passive transport.
5. Explain how each type of transport works and give examples.
6. Distinguish between hypotonic, isotonic and hypertonic solutions and explain their effect on plant and animal cells.

APPENDIX G
BLOOM'S TAXONOMY

1- **Knowledge**: Ability to recall and bring to mind the appropriate material.
2- **Comprehension:** Ability to apprehend what is being communicated and make use of the idea without relating to other ideas or material or seeing fullest meaning.
3- **Application:** Ability to use ideas, principles, theories in particular or concrete situations.
4- **Analysis**: Ability to break down communication into constituent parts to make organization of ideas clear.
5- **Synthesis:** Ability to put together parts or elements into a unified organization or whole.
6- **Evaluation:** Ability to judge the value of ideas, procedures, methods using appropriate criteria.

(Bloom, 1969)

APPENDIX H

TABLES OF SPECIFICATIONS

TEST VALIDATION 1

Place a K next to each knowledge question.
Place a C next to each comprehension question.
Place an AP next to each application question.
Place an AN next to each analysis question.
Place an S next to each synthesis question.
Place an E next to each evaluation question.

Question number	Objective	Cognitive
PART A		
Question I		
a	6	K
b	6	K
c	5	K
d	6,7	C
e	6,7	K
f	6,7	C
PART B		
Question II		
1	6	C
2	6	AP
3	6	AN
4	6	C
5	2	AN
6	1,2	C
7	6	K
8	6	C
9	6	C
10	6	K
11	6	K
PART C		
Question III		
a	3	AP
b	3	AP
c	4	K
Question IV a	7	K

b	5,6	AN
c	5,6	C
d	4	K
e	6,9	K
PART D		
Question V		
a	2,6	AN
b	2	S
c	2,6	E

TEST VALIDATION 2

Place a K next to each knowledge question.
Place a C next to each comprehension question.
Place an AP next to each application question.
Place an AN next to each analysis question.
Place an S next to each synthesis question.
Place an E next to each evaluation question.

Question number	Objective	Cognitive
PART A		
Question I		
a	1	K
b	1,5	K
c	5	C
d	3	K
e	1	K
PART B		
Question II		
1	4,5	C
2	1	C
3	3,5	C
4	2	C
5	4,5	C
6	2	K
7	4,5	K
8	3,5	AN
9	5	AN
10	2,5	K
11	2	AN
12		K
13		K
PART C		
Question III		
a	1	AN
b	5	AN
c	5	C
Question IV		
1 (a, b, c, d, e)	2,5	AP
2 a	6	C
2b	6	AN
PART D		

Question V		
a	6	S
b	6	E
c	6	C

APPENDIX I

BIOLOGY ATTITUDE SCALE

Using this scale will help you and I find out how you feel about yourself and Biology. On the following pages is a series of sentences. You are to mark your answer sheets by telling how you feel about them. As you read the sentence, you will know whether you agree or disagree. If you **strongly agree**, circle **A**. If you **agree**, but not so strongly, or you only "sort of" agree, circle **B**. If you **disagre**e with the sentence **very strongly** circle E If you **disagree**, but not so strongly, circle **D.** If you are **not sure** about question or you can't answer it, circle **C**.
Now, mark your sheet. Be sure to answer every statement. There is no "right" or wrong" answer. The only correct responses are those that are true for you.

1	I like biology more than other subjects	A	B	C	D	E
2	Biology helps the development of my conceptual skills	A	B	C	D	E
3	I like watching natural history films; I would like therefore make a career in this in this field	A	B	C	D	E
4	I like my biology teacher	A	B	C	D	E
5	Our biology teacher makes drawings or uses pictures in each practical works	A	B	C	D	E
6	We never use any biology equipment	A	B	C	D	E
7	Nature and biology is strange for me	A	B	C	D	E
8	Biology is not important in comparison with other courses	A	B	C	D	E
9	Biology knowledge is necessary for my future career	A	B	C	D	E
10	Our biology teacher makes us do active work	A	B	C	D	E
11	Our biology teacher disregard aspiration of students with bad rating	A	B	C	D	E
12	Biology is important part of our lives	A	B	C	D	E
13	I would like to have biology lessons more often	A	B	C	D	E
14	Biology knowledge is essential for understanding other courses and phenomenon	A	B	C	D	E
15	My biology teacher is my personal model, I would like to work with her	A	B	C	D	E
16	l find biological processes very interesting	A	B	C	D	E
17	biology lessons are very difficult for me	A	B	C	D	E
18	The work with living organisms in biology lessons is very interesting	A	B	C	D	E
19	I hate biology lessons	A	B	C	D	E
20	Nobody needs biology knowledge	A	B	C	D	E
21	My future career is independent from biology knowledge	A	B	C	D	E
22	during biology lessons, I am bored	A	B	C	D	E
23	Biology is our hope for solving many environmental problems	A	B	C	D	E

24	I have often difficulties to understand what we have to learn in biology	A	B	C	D	E
25	Biology is one of the easiest courses for me	A	B	C	D	E
26	I make many efforts to understand biology	A	B	C	D	E
27	The progress of biology improves the quality of our lives	A	B	C	D	E
28	I would like to be a biologist	A	B	C	D	E
29	When I prepare for biology lesson, I bring to mind equipment that we have used in biology	A	B	C	D	E
30	I like the way how biology is teaching in our school	A	B	C	D	E

APPENDIX J

BIOLOGY ATTITUDE SCALE SCORING KEY

C= Students' attitude on the importance of biology for their future career (Career)
Im = Students' attitude toward the importance of biology lessons (Importance)
In = Students' interest toward biology lessons (Interest)
E = Students' attitude toward the use of biology equipment in biology lessons (Equipment)
T= Students' attitude toward biology teacher (Teacher)
D= Students' attitude toward difficulty of biology lessons (Difficulty)

+ = Question reflects positive attitude
- = Question reflects negative attitude

Question # Category of
Question Attitude
1 In+
2 Im+
3 C+
4 T+
5 E+
6 E-
7 In-
8 Im-
9 C+
10 T+
11 T-
12 Im+
13 In-
14 Im+
15 C+
16 In+
17 D-
18 In+
19 In-
20 Im-
21 C-
22 In-
23 Im+
24 D-
25 D+
26 D-
27 Im+
28 C+
29 E+
30 D+

Scoring Directions:
Each positive item receives the score based on points
A = 5 B = 4 C = 3 D = 2 E = 1
The scoring for each negative item should be reversed
A = 1 B = 2 C = 3 D = 4 E = 5
Add the scores for each group, In, Im, C, D, T and E, to get a total for that attitude dimension

APPENDIX K

THE EXPERIMENTAL INTERVIEW QUESTIONS

1. What is the main part that you found helpful when using the science and engineering practices?
2. What is the main part that you found not helpful when using science and engineering practices?
3. Did the use of science and engineering practice help you understand the work in the biology lab?
4. Did you notice the relation (link) between classroom explanation and the lab work through the use of science and engineering practices? Where?
5. Would you like to use the science and engineering practices once again at the biology lab?
6. Do you feel that the implementation of science and engineering practices helped you perform better in terms of knowledge or skills?
7. Did you enjoy using science and engineering practices in your biology lessons?
8. Is it hard to use science and engineering practices?
9. Would you consider using science and engineering practices in studying for courses other than biology?
10. Based on your experience what changes would you make to improve the use of Science and engineering practices?

THE CONTROL INTERVIEW QUESTIONS

1. What is the main part that you found helpful when using the structured inquiry approach?

2. What is the main part that you found not helpful when using the structured inquiry approach

3. Did the use of the structured inquiry approach help you understand the work in the biology lab?

4. Did you notice the relation (link) between classroom explanation and the lab work through the structured inquiry approach? Where?

5. Would you like to use the structured inquiry approach once again at the biology lab?

6. Do you feel that the implementation the structured inquiry approach helped you perform better in terms of knowledge or skills?

7. Did you enjoy the structured inquiry approach in your biology lessons?

8. Is it hard to use the structured inquiry approach?

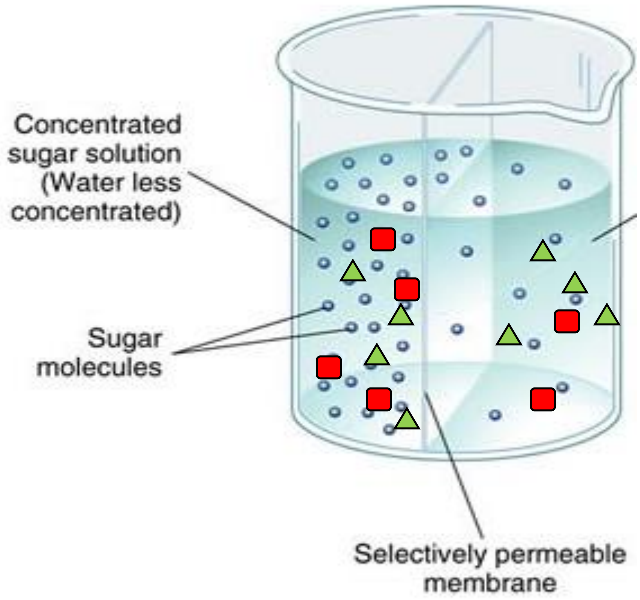
9. Would you consider using structured inquiry approach in studying for courses other than biology?

10. Based on your experience what changes would you make to improve the use of the structured inquiry approach?

APPENDIX L

DESIGN TASK ASSESSMENT

Question 1



Use the above setup and all the information provided below to answer the question(s) below.

- The left side of the beaker is highly concentrated solution that contains sugar, proteins and salt molecules.
- The selectively permeable membrane only permits the passage of molecules of a maximum size of 2 u (u stands for any unit).

Key	Size
Sugar molecule	4 u (shown in diagram above)
Protein molecule	6 u
Salt molecule3 u	

1 a. which type of transport is demonstrated in the above setup? Justify your answer.

1 b. Will the level of water change at any side? If yes, which side and why?

1 c. Explain what will happen if the selectively permeable membrane above has been replaced by another one that permits the passage of molecules of size 4.5 u? Justify your answer.

Question 2

You were given a selectively permeable membrane labeled A by your teacher and were asked to design a setup that will help you identify whether the membrane is selectively permeable for starch or protein using the following materials:

- beakers
- selectively permeable membrane labeled A
- test tubes
- tap water
- potato
- egg albumin (protein powder)
- Starch
- droppers
- salt
- plastic bags
- plastic wrap
- aluminum foil
- balances
- tap water
- Biuret solution
- Iodine solution
- concentrated sugar solution
- graduated cylinders
- glass rods
- dialysis tubing
- spatulas (spoons)
- zip lock bags

The biuret solution is a blue indicator that will help identify the presence of proteins. It changes color from blue to violet in the presence of proteins. However, it does not change color (stays blue) in the absence of proteins.

The iodine solution is a brown-orange indicator that will help identify the presence of starch. It changes from brown-orange to dark blue or dark purple in the presence of starch. However, it does not change color (stays brown-orange) in the absence of starch.

Use all the information above to answer the following questions:

2a. Schematize a labeled setup that will help you find out whether membrane A is permeable for starch or proteins. **Make sure to design the whole setup once.**
2b. Discuss and justify your labeled setup above.

APPENDIX M

RUBRIC FOR DESIGN TASK ASSESSMENT

Score	3	2	1	0
1.Assessment of Given Design				
(1a) Analysis of cellular transport process of Design Setup	- Specifies the scientific term of the process demonstrated in the given setup. - Provides an appropriate and clear justification related to water concentration or concentration gradient.	- Specifies the scientific term of the process demonstrated in the given setup. - Does not provide a clear justification related to water concentration or concentration gradient.	- Specifies the scientific term of the process demonstrated in the given setup. - The justification is missing or is incorrect if present.	- The scientific name of the demonstrated process is missing or is incorrect if present. - The justification is missing or is incorrect if present.
(1b) Analysis of water level change	- Provides a correct answer and a correct scientific justification related to concentration gradient.	- Provides a correct scientific justification related to concentration gradient but does not provide a correct answer.	- Provides a correct answer with incorrect or missing justification.	- Provides an incorrect answer or answer is missing - Provide an incorrect justification or justification is missing.
(1c) Analysis of factors affecting movement of particles	- Specifies the one type of molecule (sugar) that passes through the membrane. - Takes into consideration the particle size and concentration gradient as factors needed for passage of particles through a membrane.	- Specifies the passage of two types of molecules (salt and sugar) without taking into consideration the concentration gradient as a factor for movement of molecules.	- Specifies the passage of one or two (salt or sugar or both) types of molecules without providing a correct justification related to concentration gradient and particles size.	- Specifies the passage of protein molecules with or without other molecules or the names of the molecules is missing. - The justification is incorrect or missing if present
2. Functionality of created design				
	- The used materials are relevant. - Design takes the constraints into consideration (i.e. Setup is drawn only once). - Tests the membrane permeability for the two tested substances (protein and starch).	- The used materials are relevant. - Design does not take the constraints into consideration (i.e. Setup is drawn more than once). - Tests the membrane permeability for the two tested substances (protein and starch).	- The used materials are relevant to test the membrane permeability for one substance only (either protein or starch).	- The design includes additional or missing materials that disrupts the functionality of design - Membrane does not test permeability for any of the substances (neither protein nor starch)
3. Explanation of Design testing				
	- Explains the testing of membrane permeability in relation to two justifications: based on two substance-indicator reactions. - The justification is aligned with the drawn design.	- Explains the testing of membrane permeability in relation to two justifications based on two substance-indicator reactions. - The justification is not aligned with the drawn design.	- Explains the testing of membrane permeability in relation to a justification based on one substance-indicator reaction. - The justification is not aligned with drawn design.	- Does not provide any relevant justification related to substance-indicator reactions. - The justification is not aligned with the design.

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