

CASE-BASED LEARNING IN INTERNATIONAL BACCALAUREATE® BIOLOGY

by

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ABSTRACT

This classroom research study investigated the effect of case-based learning on student's problem-solving skills in a senior International Baccalaureate® biology class. Students participated in two nontreatment (evolution and the immune system) and two treatment units (the respiratory and circulatory systems). Prior to the start of the investigation, students completed a Problem-Solving Self-Perceptions Survey. This survey was completed at the end of the investigation as well. At the start of each unit, students completed a problem-solving assessment with questions related to the content of the unit. Students completed another problem-solving assessment at the end of the unit as part of the end of unit exam. Students were also interviewed about their problem-solving experience and approach before and after the study. Data collected from the Problem-Solving Self-Perceptions Survey were analyzed using the Wilcoxon Signed Rank Test. Student performance on the pre- and post-unit problem-solving assessments were evaluated using normalized gains. Both analysis tools failed to show a statistically significant difference between the treatment and nontreatment. These results suggest that using case-based learning in the classroom does not significantly improve student's problem-solving skills. However, student's expressed greater interest in studying real-life problems and students were observed to be more engaged in the learning activities and the small group collaboration.

INTRODUCTION AND BACKGROUND

Context of the Study

In my seven years of teaching, critical thinking and problem-solving have always been skills that I value and strive to emphasize in my classroom, no matter the grade level. I believe students who know how to think critically about information and can solve various problems are better prepared for lives outside of the classroom. However, during this same time, I have also discovered that these skills are challenging for students.

My current teaching position is with North Star Charter School (NSCS) teaching high school biology, chemistry and International Baccalaureate® (IB) biology. It is a K-12 charter school located in Eagle, Idaho with a total enrollment of 997 students, 171 of these are high school students (M. Anderson, personal communication, December 2, 2019). Eagle is one of the more affluent communities in the state of Idaho. The average income of a family living in Eagle is approximately \$115,00 per year versus a \$67,000 per year state average income. The poverty rate in Eagle is nearly 7% while the state average is 14.5%. Individuals living in Eagle also attain higher education than the state average with 28% possessing a bachelor's degree and 17% possessing a graduate degree, while the state averages are 18% and 8.5% respectively (World Population Review, 2019).

The high school follows a block schedule with 90-minute class periods. Students attend high school at NSCS for a variety of reasons including, the smaller community, the academic rigor, the focus on business and economics, and the IB offerings. The population of NSCS is representative of its community demographics. The school is

primarily Caucasian with 89% of students identifying as white, 4% identify as Hispanic, and 3.5% identify as Asian. The school does not provide a school lunch program, so free and reduced lunch is not available. Only 5.5% of the student population is on an individualized learning plan (IEP). The student population of NSCS is 49% female (M. Anderson, personal communication, December 2, 2019).

The high school science sequence at NSCS begins with biology in ninth grade, chemistry in tenth, IB biology in eleventh, and then students can either continue with IB biology as seniors or participate in an internship program. The two primary assessments of students in IB biology are the internal assessment (IA), where students design and conduct their own scientific investigation, and a three-paper end of course exam. The first paper is a 40-question multiple choice exam. The second and third papers are free-response questions that include critical thinking and problem-solving. The exams and IA are scored on a 1-7 scale; a score of four on each paper and the IA is considered passing. Because of the rigor of the program, students are very focused on grades. However, that focus on getting A's doesn't always translate into an understanding of the content sufficient for success on critical thinking and problem-solving questions. Part way into my first year at NSCS, I was surprised to see how much my students struggled with problem-solving activities and exam questions that expected knowledge application.

At the conclusion of my first year at NSCS I began researching instructional methods that emphasized knowledge application, critical thinking, and problem-solving. In my research I came across case-based learning (CBL). I had heard of CBL before and even looked at using case studies when I was teaching middle school science but had difficulty finding case studies that were appropriate for sixth, seventh and eighth graders.

A brief search on The National Center for Case Study Teaching in Science website revealed that resources appropriate for high school students and related to the IB content were extensive. But my problem was greater than access to resources, I realized my students needed more than just exposure to critical thinking activities and questions, they needed to be taught how to approach critical thinking problems.

One of the advantages of CBL is the flexibility this strategy allows for teaching. Cases can be taught using debate, mock trials, Socratic discussion, and team-learning formats (Herreid, 2007). Team-learning particularly appealed to me because the method could be broken down into individual responsibilities and team responsibilities. Individual students would be expected to prepare by reading the content information, conducting research, and formulating initial responses to case questions. In teams, students would work through cases that required them to apply their knowledge to solving realistic problems. This method would help to ensure all learning outcomes of the course are addressed and increase student depth of knowledge through team discussion and problem-solving. It could also be implemented in my courses that only meet every other day by requiring completion of the individual components of the team-learning method outside of class. The team-learning aspects could then be conducted as part of face-to-face class time.

Focus Question

Business schools have been teaching students how to approach real problems using a systematic, stepwise approach. Outlined in *Learning with Cases*, this problem-solving approach takes students through ten steps designed to evaluate the problem, outline possible solutions, make decisions, and predict outcomes (Flynn & Klein, 2001).

This same approach could be implemented in my IB biology courses to teach students how to approach case studies and learn to problem-solve. My focus question was, What is the effect of case-based learning on IB biology students' problem-solving skills?

CONCEPTUAL FRAMEWORK

History of Case-Based Learning

Case-based learning (CBL) is a teaching strategy that has been implemented in a variety of college graduate and undergraduate programs for more than a century (Herreid, 2005; Servant-Miklos, 2019). CBL involves identifying and evaluating a problem. Through discussion and questioning, students are guided to think critically about the problem and information presented. Solutions or recommendations are then proposed and discussed, which leads to the generation of alternative solutions or recommendations. Finally, students make predictions regarding the potential outcomes of implementing their recommendations. Each step is achieved through collaboration and problem-solving (Flynn & Klein, 2001; Herreid, 2007).

A learning system based entirely on the study of current and past law cases was adopted by Harvard Law School in 1870 under the direction of Prof. Christopher Columbus Langdell. This approach influenced the development of similar learning methods in Harvard Medical School in 1900 and Harvard Business School in 1920. Surprisingly, the case method was abandoned shortly after its implementation in the medical school as cases were thought to be closed problems with a single answer. With rapid discoveries occurring in medical science in the early 1900's, medical knowledge was no longer considered fixed, thus, medical learning required a more open approach. However, the case method continues to be used in the business school today. While the medical school wished to use the case method for the learning of content, the business school was more interested in using the case method to teach analytical and problem-solving skills (Servant-Miklos, 2019).

Modern Education Theory

Modern postsecondary and K-12 education reforms are still attempting to address the issues recognized by these early education leaders. The American Association for the Advancement of Science (AAAS) identified six essential skills that students need to develop as a part of undergraduate science education. These six items are (a) applying the process of science, (b) the use of quantitative reasoning, (c) using modeling and simulations, (d) tapping into the interdisciplinary nature of science, (e) communicating and collaborating with other disciplines, and (f) understanding the relationship between science and society. The AAAS also advocates for a student-centered approach to teaching and learning over the traditional teacher-centered approach (Brewer & Smith (Eds.), 2015). Unlike traditional classrooms where lecture is the primary mode of instruction and assessment is based on the memorization of scientific facts, in a student-centered classroom, learning is directed by the students. Collaboration, discussion, and inquiry are key components in this type of classroom (Barnes, 2013; Lee, 2012).

Designers of the Next Generation Science Standards (NGSS) also recognized the value of a student-centered approach to science learning. The writers note how science education has emphasized lectures, note-taking and the memorization of facts instead of learning to think scientifically. The authors state that to be successful and ready for college, students need to be able to approach unique problems. The authors shared that students are better able to accomplish this if they have a solid understanding of fundamental science concepts and experience applying the practices routinely used by scientists. In fact, ACT argues for a deeper understanding of fundamental science concepts and a stronger emphasis on science process and inquiry skills. Both the College

Board and ACT have revised their examinations to incorporate questions that focus on skill application (NGSS Lead States, 2013).

Advantages of Case-Based Learning

CBL incorporates a variety of 21st century skills such as collaboration and teamwork, critical thinking, problem-solving, information literacy, and social responsibility critical to modern science education reform. Implementation methods are flexible enough for use across curricula and content areas. Through CBL implementation, classrooms become much more student-centered and provide opportunities to practice thinking like scientists (Herreid, 2005; Lee, 2012).

Additional advantages have been identified that support the implementation of CBL. Women and minority groups tend to avoid or leave the STEM fields due to poor teaching practices that emphasize memorization and fail to incorporate application and connections to real problems and situations (Lunderberg & Yadav, 2006a). Research evaluating student perceptions of science content and attitude toward science courses show that female student attitudes, perceptions, and course enjoyment improve when CBL is the instructional method (Murray, 2016). Student engagement and attitudes have been found to improve in courses where CBL is used and students state that they prefer the CBL instructional method to traditional lecture (Flynn & Klein, 2001; Nair, Shah, Seth, Pandit, & Shah, 2013; Williams, 2005; Yadav et al., 2007). Class attendance was also found to increase on days where cases were presented (Lunderberg & Yadav, 2006b). Increased content retention and deeper learning have also been associated with CBL (Kulak, Newton, & Sharma, 2017). One study showed that students preferred a lecture style environment but performed better on exams in the case study environment

(Yadav et al., 2007). Researchers also found that nursing students participating in a CBL program performed better on critical thinking tasks related to nursing than their peers in a non-CBL program (Kaddoura, 2011). Faculty using cases in their classrooms noted that students were better able to make connections to other content areas, could view issues from multiple perspectives, strengthened their critical thinking skills, and increased their ability to discuss ethical issues (Yadav et al., 2007). Through the use of CBL, some students were able to correct their own misconceptions (Rybarczyk, Baines, McVey, Thompson, & Wilkins, 2006). The benefits of CBL identified in the research are the same skills identified as the most valued by employers according to research done by the National Association of Colleges and Employers (NACE), particularly critical thinking/problem-solving and teamwork/collaboration (NACE Staff, 2019, Mar 29). Given that one of the key goals of secondary education is college and career readiness, CBL appears to be a learning method that can successfully support this goal.

Characteristics of Successful CBL

While CBL has some distinct advantages to other forms of instruction, not all cases are effective. The National Center for Case Study Teaching in Science surveyed all of its members about their favorite cases and what characteristics made them a favorite (Herreid, Schiller, Herreid, & Wright, 2012). Favorite cases were found to share a number of characteristics. Shorter cases that could be completed in one to two class periods were preferred by members, additionally, cases must meet one of the course learning objectives. Other characteristics of favorite cases included practicality, relevance, realism, and open-endedness. The most preferred case styles were problem-based and interrupted. Interrupted cases are those that are designed to be presented to

students in parts. Students are first introduced to the problem and then, over time, are provided with additional information to help them understand the case and develop solutions. While many cases tend to be problem-based, this is not a requirement of case design. Selecting or producing a well-written case is an essential element of CBL implementation (Herreid, Schiller, Herreid, & Wright, 2012).

Beyond the selection of the case, teacher preparation is another key factor in CBL success. Teachers need to understand the cases they use and the goals they have for student learning. Teachers also need to prepare a variety of discussion questions prior to introducing the case (Herreid, 2007). The success of a CBL lesson is not just the teacher's responsibility, students also need to prepare. Discussion quality during a CBL lesson greatly improves when students have prepared beforehand, higher quality discussions lead to greater student achievement (Flynn & Klein, 2001). If students and teachers are committed to CBL and willing to invest the time required for preparation, the literature is clear about the positive student outcomes related to attitude, engagement, and higher order thinking skills.

Barriers to Successful Implementation

A number of barriers exist to implementing CBL effectively, making it difficult for teachers to overcome some challenges. First, most teachers are unfamiliar with the case teaching method which can be intimidating, particularly to an inexperienced educator. This teaching and learning method may also be unfamiliar to students. They may become frustrated when questions are responded to with additional questions, instead of answers (Harvard Kennedy School, n.d.; Mostert, 2007; Yadav et al., 2007). Second, case preparation can be labor intensive, both for teachers and for students. Cases

need to be read ahead of time and linked to course objectives. Discussion questions also need to be developed to guide student discussions toward understanding key scientific concepts and understanding. Students need to read the cases prior to the class discussions, preparing notes documenting their insights, understandings and reflection (Harvard Kennedy School, n.d.; Mostert, 2007; Yadav et al., 2007). Third, questioning and discussion techniques can also prove challenging for teachers who are not experienced in CBL. Quality discussions are essential to a good CBL lesson and it can be difficult to get all students to actively participate in the discussion. For example, some students may monopolize the conversation causing other students to completely tune out. Additionally, teachers may find it challenging to keep the discussion focused on the objective of the case, which may mean that the original objective(s) of the case and learning target(s) of the course are not addressed. Some instructors have a hard time formulating questions during case discussions that will continue the discussion's momentum (Harvard Kennedy School, n.d.; Mostert, 2007). Finally, educators have expressed difficulty in developing assessments that adequately evaluate student learning. Case-based learning relies heavily on small group collaboration and discussion which can make it difficult to assess individual student learning (Yadav et al., 2007).

Some practical challenges also exist to CBL implementation. CBL is best implemented in small groups. As class sizes increase it becomes less and less likely that all students will be active participants in the discussion. Given the current size of most K-12 and undergraduate classes, instructors may decide that CBL is not a good fit based on their class size. Cases also take much more time to work through and process. Educators have limited time within the school year to address all of their state's standards. Teachers

may determine that an extensive investigation through a case study is not the most effective use of their class time (Mostert, 2007).

METHODOLOGY

Case-Based Learning Treatment

This capstone project evaluated the effects of case-based learning on problem-solving skills in seniors participating in International Baccalaureate® (IB) biology. Problem-solving is a skill valued by the IB and evaluated on the end of course assessment. Problem-solving is also an area where students traditionally have difficulty, particularly if data are included as part of the question. Second year IB biology students were asked to participate in this capstone project and informed that participation would not impact their grade or class standing. Data was collected from November 2019 through March 2020. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A).

During the treatment units, students explored complex topics and real-world problems through case studies, in addition to the regular class labs. In small groups, students read the background information and worked together to discuss and respond to the case questions. Often, students needed to conduct additional research through web-based resources to develop an understanding of the problem. Occasionally, background information was assigned as homework for students to complete in order to be prepared for the team discussion and investigation in class. During the nontreatment units, case studies were replaced with lecture and notes sessions. Treatment units included the respiratory system and circulatory system. Nontreatment units included evolution and the immune system.

Data Collection Tools and Strategies

Prior to implementation of the case-based learning method, students were asked to complete the Problem-Solving Perceptions Survey (Appendix B). The four-option Likert-type survey asked students to respond Strongly Agree, Agree, Disagree or Strongly Disagree to identify their perceptions regarding their problem-solving approach and attitude. The Problem-Solving Perceptions Survey provided quantitative baseline data to help answer the focus question: What is the effect of case-based learning on IB biology students' problem-solving skills? The Problem-Solving Perceptions Survey was given again at the end of the project to compare responses and determine if any change had occurred in students' perceptions of their problem-solving skills or attitudes. The data collected was organized into categories reflecting attitude, perseverance, and problem-solving approach. Percentages of answers for each response were calculated for the pre-treatment survey and again for the post-treatment survey. Comparisons between the pre- and post-treatment surveys helped show any changes or transformations in student perceptions of their problem-solving attitude or approach and were used to address the focus question. Pre- and posttreatment question responses were compared and evaluated using the Wilcoxon Signed Rank Test to determine if the difference between the responses was significant.

To evaluate students' problem-solving ability, students were presented with IB Biology Problem-Solving Questions from the IB biology textbook as class warm-up tasks prior to the start of each treatment and nontreatment unit (Appendix C). These same questions were presented again at the end of the unit they were given and compared to students' initial responses. IB Biology Mark Schemes were used to evaluate pre- and

post-unit responses (Appendix D). Individual student responses were compared using normalized gains calculated as average of gains. The normalized gain was calculated to determine differences in student problem-solving. Normalized gains of less than 0.3 were considered low gains, 0.3 to 0.7 were considered moderate gains, and normalized gains greater than 0.7 were considered high gains (Hake, 1998). This data was used to quantitatively support a response to the focus question.

Students were selected at random to respond to Pre- and Post-Treatment Student Interview Questions (Appendix E). Pre-treatment questions asked about student strategies for approaching complex problems, their experience with problem-solving, and their attitude when faced with difficult problems. During the post-treatment interview, the same students were asked about any changes they felt had occurred in their problem-solving approach, strategies they tried when facing a difficult problem, and additional experience they had acquired as a result of the treatment. Interviews were conducted to better understand student's feelings about the treatment vs. nontreatment and any effect they felt it had on their problem-solving approach or attitude. Student interviews were triangulated to qualitatively support the response to the focus question along with the quantitative data collected and evaluated from the surveys and problem-solving questions (Table 1).

Table 1. Data Triangulation Matrix.

Focus Question	Data Source 1	Data Source 2	Data Source 3
What is the effect of case-based learning on IB biology students' problem-solving skills?	Pre- and Post-Treatment Problem Solving Survey	Treatment and Nontreatment Problem-Solving Questions	Pre- and Post-Treatment Interview Questions

DATA ANALYSIS

Results

The International Baccalaureate® (IB) Biology Problem-Solving Questions administered in both the treatment and non-treatment units assessed student proficiency in using data to solve unique content related problems. Pre- and post-assessments produced normalized gains of 0.09 and 0.37 in the treatment units and 0.33 and -0.07 in the nontreatment units ($N=20$). Normalized gain scores less than 0.3 indicate a small effect on student performance from pre-assessment to post-assessment, while scores between 0.3 and 0.7 indicated a moderate effect. The negative normalized gain for the immune system unit indicated that more students performed better on the pre-assessment than the post-assessment (Figure 1).

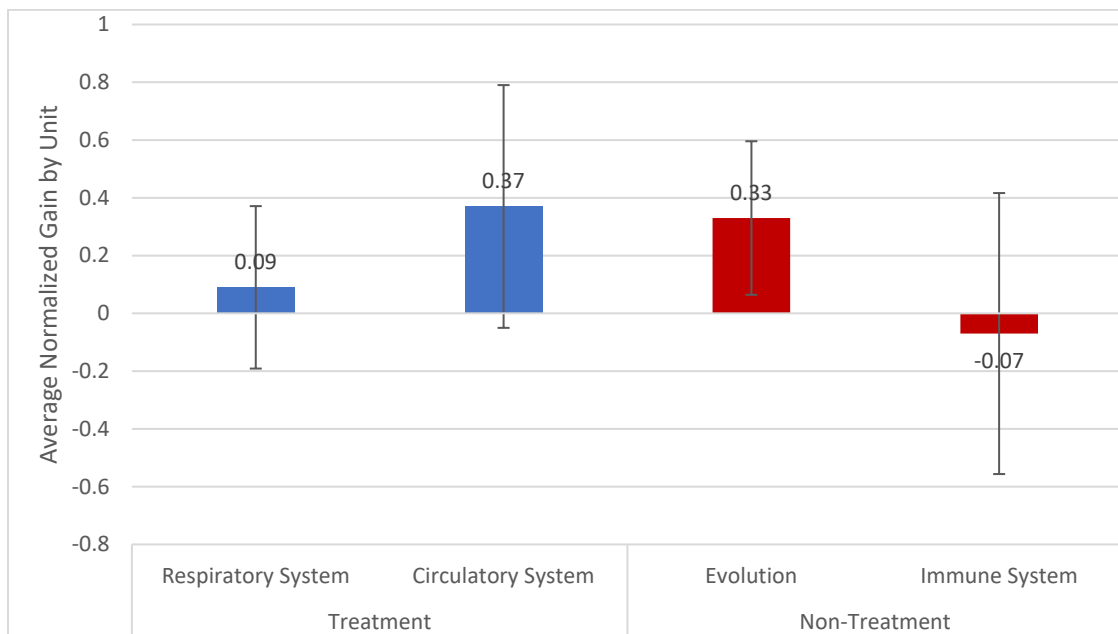


Figure 1. Treatment and non-treatment average normalized gain for pre- and post-assessment problem-solving questions with standard deviation error bars, ($N=20$).

The Problem-Solving Perceptions Survey collected student responses regarding their perceived problem-solving attitude, perseverance, and approach pre- and post-treatment. A W-value of 7 ($W\text{-critical}=2$, $p<0.05$) was produced from the Wilcoxon Signed Rank Test, which indicated that the result was not significant. Survey results were also evaluated by common themes of student attitude toward problem-solving, student perseverance in problem-solving, and student approaches to problem solving. Overall, student problem-solving attitude improved post-treatment. When asked if problem-solving was a skill students could practice, 36.8% more students strongly agreed with this statement post-treatment. Additionally, 25.2% more students strongly agreed that they could identify several ways they use problem-solving in their lives. This data are supported by student post-treatment interview responses. When asked if there was anything else she wanted to share, one student responded, “I really enjoyed the case studies. I like having actual life problems and learning how to use my knowledge.” [sic] When asked if students thought it unfair to solve problems that were not similar to problems they had already solved, the percentage of students either disagreeing or strongly disagreeing with the statement increased by 21.1% (Figure 2).

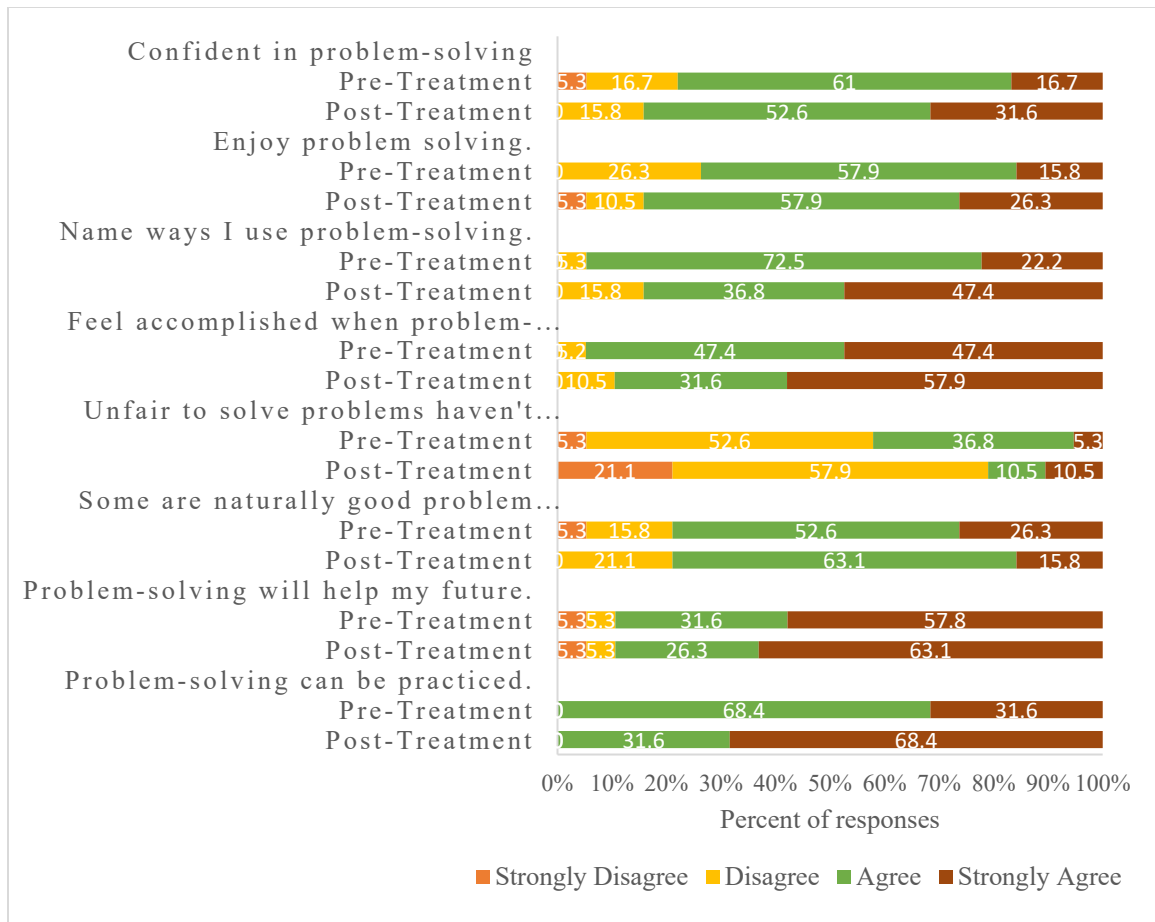


Figure 2. Results of student self-perceptions of problem-solving attitude from the pre- and post-treatment Problem-Solving Perceptions Survey, (N=19).

Student problem-solving approach also transformed as a result of the case-based learning treatment. When asked if encountering a problem students try to make connections to things they have already learned, the percentage of students strongly agreeing increased 26.3% post-treatment. Students interviewed post-treatment confirmed these results when asked if there was anything they wanted to share about the case-based learning treatment. One student stated, “The cases related to real science concerns. I enjoyed that part.” [sic] When asked how his problem-solving approach had changed after participating in case-based learning he responded, “I am more open to different ways of solving problems.” [sic] On the post-treatment survey, the percentage of students

strongly agreeing that collaborating with others helps them solve problems increased by 24.3% (Figure 3).

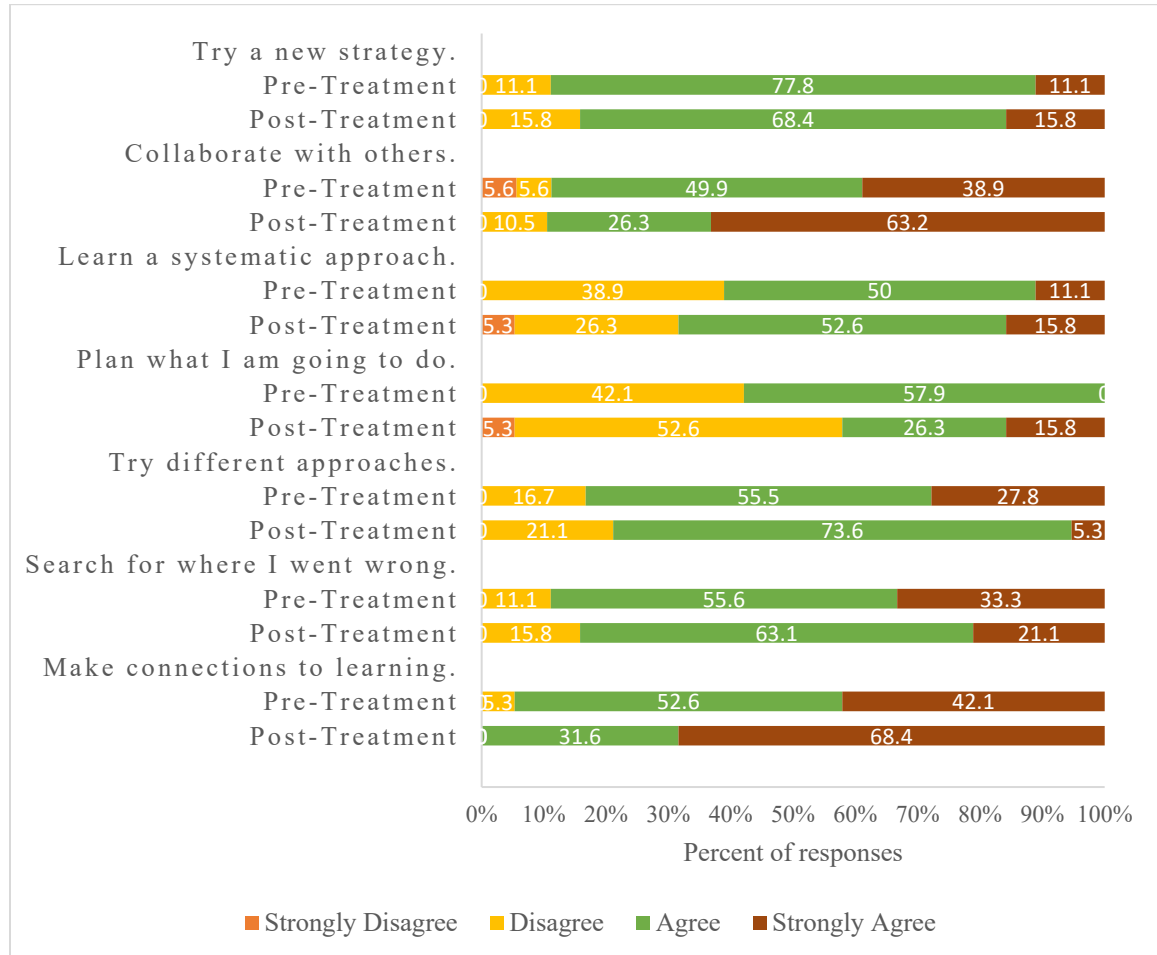


Figure 3. Results of student self-perceptions of problem-solving approach from the pre- and post-treatment Problem-Solving Perceptions Survey, ($N=19$).

Student self-perceptions of perseverance during problem-solving transformed only slightly. The percentage of students who agreed and strongly agreed when asked if they are certain they can figure out how to solve challenging problems increased 26.5% post-treatment (Figure 4). During student interviews, several students identified real situations where they have persevered through challenges, including business internships, IB internal assessments, extended essays, and community service projects.

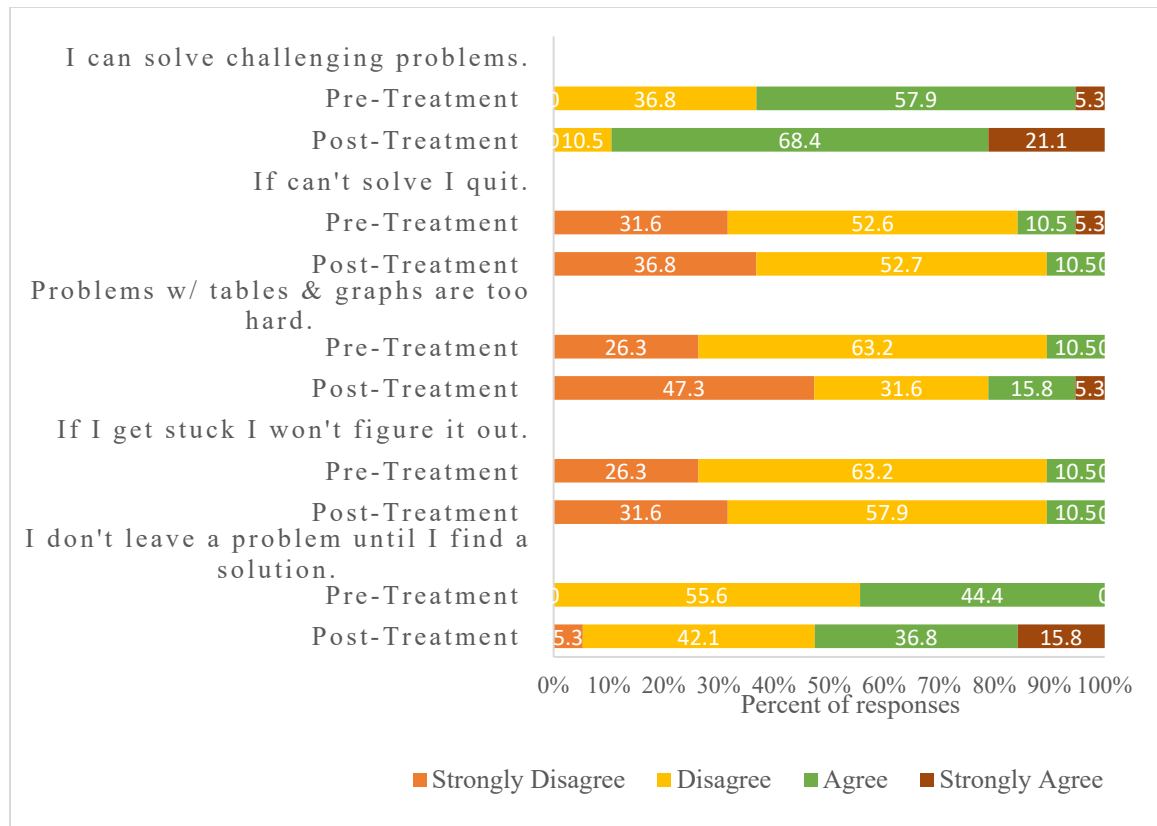


Figure 4. Results of student self-perceptions of perseverance in problem-solving from the pre- and post-treatment Problem-Solving Perceptions Survey, (N=19).

CLAIM, EVIDENCE AND REASONING

Claims from the Study

Based on student performance on problem-solving assessments, case-based learning (CBL) does not appear to significantly impact student's problem-solving skills in International Baccalaureate® (IB) biology. However, student attitude and confidence increased after participation in CBL. In addition, student engagement and interest also increased. Students expressed enjoying the opportunity to apply their learning and knowledge to real-life situations.

There are limits to the conclusions that can be drawn from the data collected during this study. The final nontreatment unit was only partially completed prior to the closure of North Star Charter School due to COVID-19. The student learning experience and environment changed dramatically as a result. This may have impacted student performance on the post-unit problem-solving assessment. Also, the pre-unit and post-unit problem solving assessments were related to the unit content and therefore did not strictly assess problem-solving ability. Student performance on the problem-solving questions may be more the result of increased student understanding of the content instead of improved problem-solving skill.

Data collected during this study showed that student problem-solving approach changed very little to not at all. This is confirmed by student interviews that acknowledged a greater consideration for alternative problem-solving strategies but that CBL did not change their problem-solving process. This may be the result of student's extensive prior problem-solving experience as well as the lack of specific problem-solving instruction provided during the study.

Value of the Study and Consideration for Future Research

One advantage of CBL mentioned repeatedly in the literature is increased student engagement (Flynn & Klein, 2001; Nair et al., 2013; Williams, 2005; Yadav et al., 2007). Every student interviewed mentioned enjoying the opportunity to apply their classroom learning to real-life situations and problems although students were not asked about their engagement in the treatment. This would suggest that the impact on their experience was significant enough to mention even though they were not asked about it directly.

Additionally, during the treatment units, student collaboration increased as cases were designed as group investigations. This problem-solving approach showed the greatest change from pre- to post-treatment on the Problem-Solving Perceptions Survey. During interviews, students mentioned several times how they relied on others to get help when solving challenging problems. Teamwork and collaboration are two of the key skills identified as desirable by employers (NACE Staff, 2019, Mar 29).

Future Studies

Future studies related to CBL should include the effect of instruction in specific problem-solving strategies in conjunction with cases. One weakness in the study was the limited transformation in student approach to problem-solving. All students interviewed stated that they had not changed their problem-solving approach as a result of CBL, however, instruction in problem-solving strategies was not a part of this study. It is possible that specific instruction in problem-solving approaches along with CBL could produce a greater transformation in this area and provide students with a variety of problem-solving strategies.

Another limitation in this study was time. Only two units were presented and investigated using CBL. It is possible that the use of CBL in classroom instruction requires more time to produce some of the outcomes identified in the literature, particularly those noting improved critical thinking, problem-solving and deep learning (Yadav et al., 2007). Future studies should include more instructional units using CBL to better understand its effect on problem-solving.

Finally, this study was intended to determine if using CBL in classroom instruction would improve student's problem-solving skills. However, the problem-solving assessment tools used in this study were limited in their ability to assess problem-solving outside of content knowledge. Students who had a better understanding of the content could perform better on these assessments without necessarily improving their problem-solving ability. Future studies should incorporate the use of assessments where the focus is on problem-solving, not content understanding in the context of a problem.

Impact of Action Research on the Author

As a result of my participation in this educational study based on the action research model, I have discovered the value in conducting action research in my classroom. I have learned about how my students prefer to learn. I have discovered the types of learning activities that increase their interest and engagement. Teachers are often asked by students, "Why are we learning this?" I have sometimes struggled in the past to answer this question for my students. Some content can be challenging to connect to the real world. However, during the CBL units, I was not asked this question. My students are not shy about sharing their opinions regarding learning activities. I have created a safe space for them to openly share what is and isn't working. Investigating science content

through realistic problems provided my students with the context for why they were learning something.

My participation in this educational study has also made me a more observant and reflective teacher. I pay closer attention to how students respond to learning activities. I began recording my observations and experiences at the end of each day, paying particular attention to elements that were successful and those that were not. As a result of my reflections I am more inclined to make changes to my instruction to improve student engagement and learning based on observations and student feedback. One of those key observations and changes is the inclusion of more opportunities for meaningful collaboration among my students. I observed more productive communication during the CBL units than I had during any other units all year. Students were tasked with researching certain aspects of the cases and sharing their learning with the rest of their team. Most students took this seriously and came to their groups prepared to teach them what they had learned. Conversations were not superficial, but meaningful to student learning and developing solutions to the problems presented in the cases.

Finally, I see the importance of collecting data when implementing changes in the classroom. In the past, I have made changes based on my observations and feedback from students but failed to collect data regarding those changes to evaluate the true impact on student performance or engagement. Data collection and analysis is important in this process to ensure that changes I make in the classroom are improving student's learning experience.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL



**INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165**

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MEMORANDUM

TO: Crystal Davidson and John Graves

FROM: Mark Quinn *Mark Quinn*
Chair, Institutional Review Board for the Protection of Human Subjects

DATE: November 13, 2019

RE: "What is the Effect of Case-Based Learning on IB Biology Students' Problem-Solving Skills?" [CD111319-EX]

The above research, described in your submission of November 12, 2019, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- X (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- X (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation; and (iii) the information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by section 16.111(a)(7).
- _____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- _____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- _____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- _____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B

PROBLEM-SOLVING PERCEPTIONS SURVEY

Student participation in this survey is voluntary. Non-participation will not impact student grades or class performance.

Problem-Solving Perceptions Survey

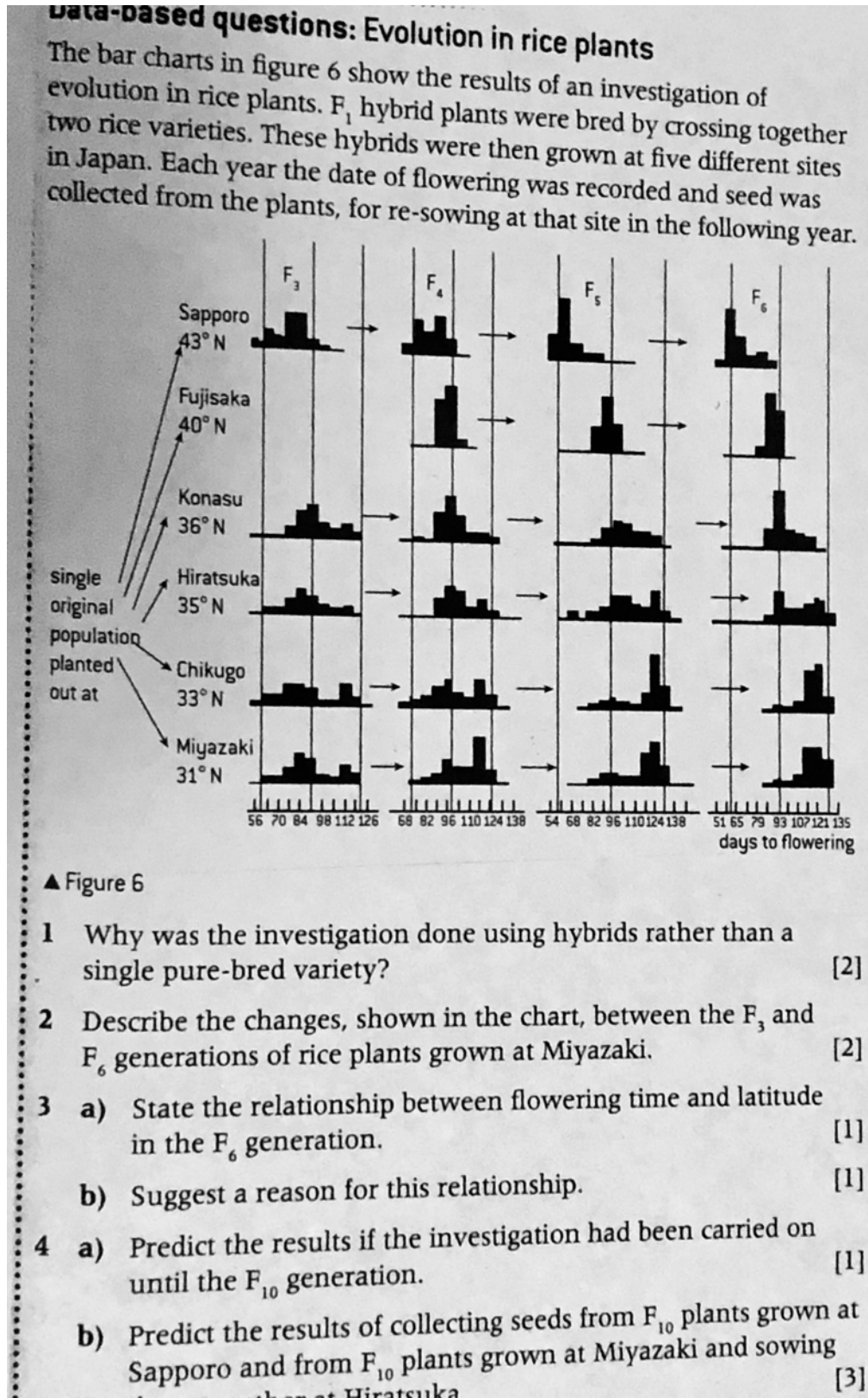
Place a check in the box that best fits how you describe yourself.

Problem-Solving Statement	Strongly Disagree	Disagree	Agree	Strongly Agree
1. I am confident in my ability to solve problems.				
2. I enjoy problem-solving tasks.				
3. I can name several ways I use problem-solving in my life.				
4. I'm certain I can figure out how to solve challenging problems.				
5. If I cannot solve a problem quickly, I quit trying.				
6. Problems that include tables or graphs are too challenging for me.				
7. I feel accomplished when I solve a problem.				
8. When I have trouble solving a problem, I try a new strategy.				
9. Collaborating with others helps me to solve problems.				
10. I think it is unfair to expect me to solve problems that are not similar to problems I have already solved.				
11. I prefer to learn systematic approaches to problem-solving.				
12. When I approach a problem, I plan what I am going to do.				
13. Some people are naturally good at problem-solving.				
14. When faced with a challenging problem, I try different approaches until I reach a solution.				
15. When I have difficulty solving a problem, I search for the point where I went wrong.				
16. If I get stuck on a problem, there is no chance I will figure it out on my own.				
17. Problem-solving will help me in my future career.				
18. When I encounter a problem, I try to make connections to things I have already learned.				
19. I don't leave a problem until I find a solution.				
20. Problem-solving is a skill you can practice.				

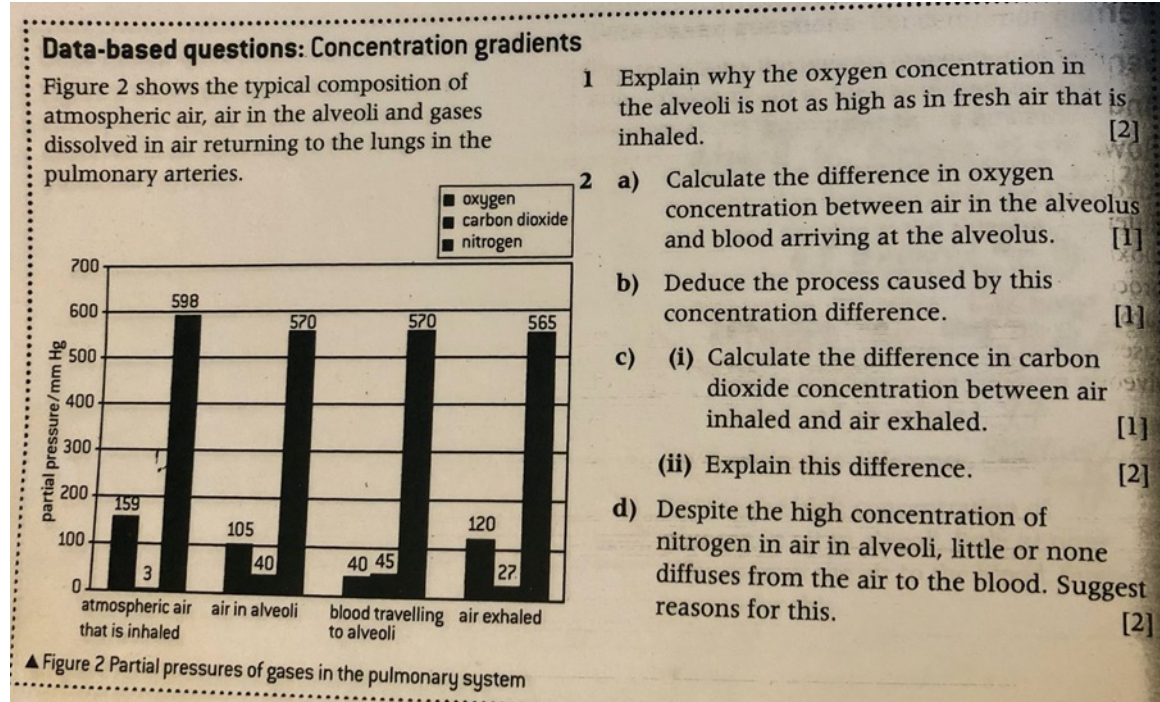
APPENDIX C

IB BIOLOGY PROBLEM-SOLVING QUESTIONS

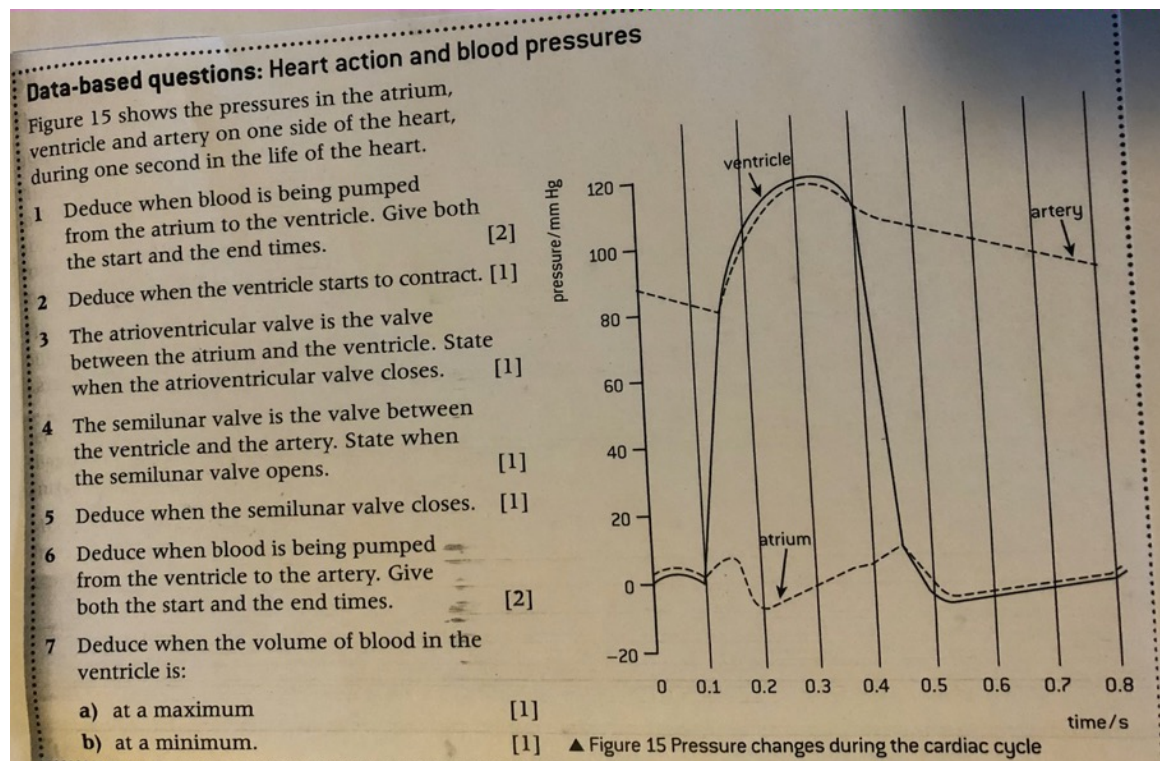
Evolution Unit Problem Solving Question



Respiratory System Unit Problem Solving Question



Circulatory System Problem Solving Question

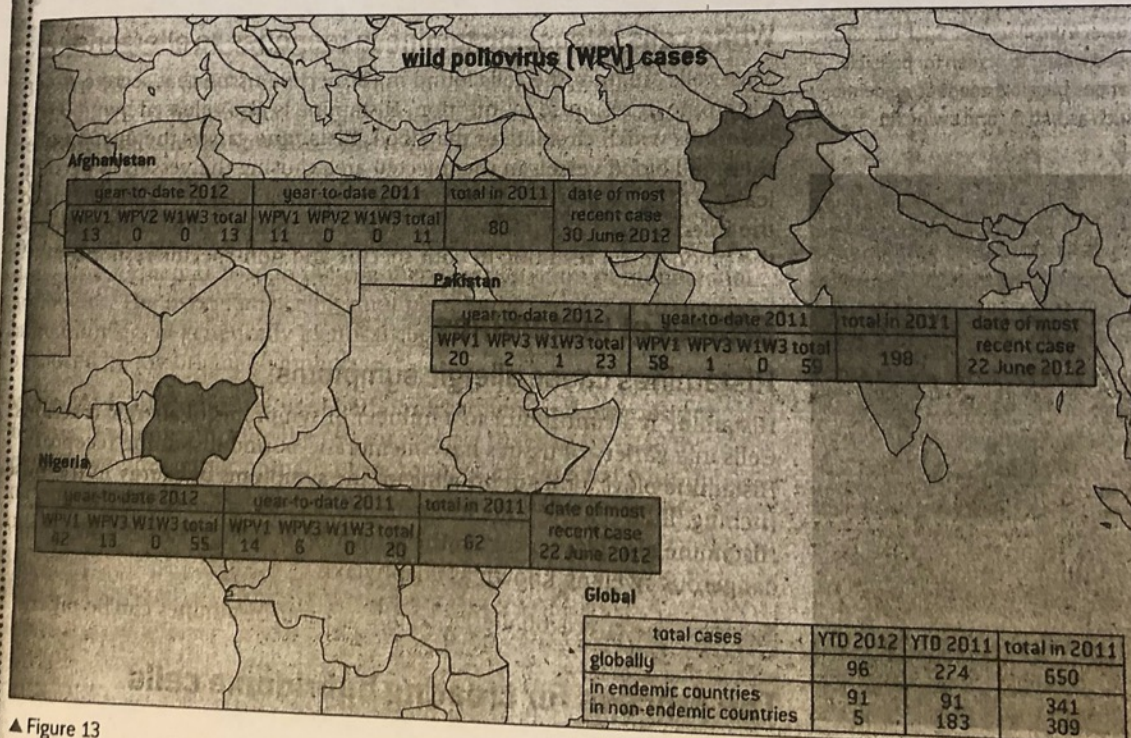


Immune System Unit Problem Solving Question

Data-based questions: Polio incidence in 2012

Figure 13 provides data about polio incidence in the three countries where wild polio was still endemic as of mid-2012.

- 1 Define the term "endemic" (1)
- 2 Identify the three countries where polio was still endemic as of mid-2012. (1)
- 3 Identify the strain of polio virus which is the most prevalent. (1)
- 4 Identify one country where the situation appears to have improved between 2011 and 2012. (2)
- 5 Given that in 1988 there were an estimated 350,000 cases of polio globally, discuss the success of the polio eradication programme. (5)
- 6 Suggest some of the challenges an epidemiologist might face in gathering reliable data. (5)
- 7 Research to find the status of polio eradication in these countries.



▲ Figure 13

APPENDIX D

IB BIOLOGY MARK SCHEMES

Evolution Unit Problem Solving Question Mark Scheme

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1. hybrids have genetic variety but pure-bred varieties do not; genetic variety is needed for natural selection;
2. mean flowering date becomes later; variation in flowering dates reduced;
3. a) later flowering times in lower latitudes / further south;
b) shorter growing season further north / higher latitudes so plants that flower later will not have enough time to develop seeds and fruits;
4. a) less variation and stronger correlation between latitude and flowering time;
b) poor performance in the first year with some flowering too early and some too late; cross-breeding between the two varieties produces plants that flower at intermediate time; in following years the intermediate flowering plants become dominant;

Respiratory System Unit Problem Solving Question Mark Scheme

1. inhaled air mixes with air in alveolus which has a lower oxygen concentration / is stale air; some oxygen has diffused into capillaries that surround the alveoli due to low partial pressure of oxygen in those capillaries;
2. a) $\frac{105 - 40}{40} \times 100\% = 163\%$; the partial pressure of oxygen is 163% higher in the alveolus;
b) diffusion;
c) (i) $\frac{3 - 27}{3} \times 100\% = 800\%$; 800% increase in CO₂ concentration between inhaled and exhaled air;
(ii) CO₂ produced by cell respiration; CO₂ enters blood as it flows through tissues of the body; CO₂ has diffused out of the blood into the alveolus raising the CO₂ concentration in the alveolus;
d) nitrogen concentration in blood is already as high as in the atmosphere; nitrogen not used by tissues of the body; no concentration difference between blood and air in alveolus; as many carbon dioxide molecules move from blood to air as from air to blood / no net movement;

Circulatory System Unit Problem Solving Question Mark Scheme

1. blood is pumped from atria to ventricles 0 seconds to 0.1 seconds (N.B the slight rise in atrial pressure at 0.15 seconds is probably due to the AV valve bulging back into the atria as ventricular systole starts;)
2. ventricles start to contract at 0.10 seconds;
3. AV valve closes at 0.1 seconds (atrial pressure falls below ventricular pressure);
4. SL valve opens at 0.15 seconds (ventricular pressure rises above arterial pressure);
5. SL valve closes at 0.4 seconds (ventricular pressure falls below arterial pressure);
6. blood is pumped from the ventricle to the artery from 0.15 to 0.4 seconds;
7. a) blood in the ventricle is at a maximum at 0.1 seconds (just before the SL valve opens);
b) blood in the ventricle is at a minimum at 0.4 seconds (at the end of ventricular systole);

Immune System Unit Problem Solving Question Mark Scheme

1. endemic: native to the area;
2. Afghanistan, Pakistan and Nigeria;
3. WPV1;
4. Pakistan is the only country where year to date comparison shows a total decline;
5. eradication programme appears to have led to a significant reduction in the total number of cases; only $650/350000 = 0.2\%$ of the number of cases have been reported; worsening in two countries; disease is persistent / eradication has not been achieved;
6. lack of access to populations in remote areas; lack of trust between affected individuals and epidemiologists; lack of recognition of mild cases; mis-diagnosis; language barriers; death before identification;

APPENDIX E

PRE- AND POST-TREATMENT STUDENT INTERVIEW QUESTIONS

Student participation in this survey is voluntary. Non-participation will not impact student grades or class performance.

Student pre-treatment interview questions:

1. What is your process or approach to solving problems?
2. What experience do you have with solving unique or challenging problems?
3. What do you do when you are having difficulty solving a problem?
4. Is there anything else you want me to know or that you would like to share?

Student post-treatment interview questions:

1. Has your problem-solving approach changed since participating in this course?
2. What additional experience have you gained in solving unique or challenging problems?
3. What strategies did you try when you were having difficulty solving a problem?
4. Is there anything else you want me to know or that you would like to share?