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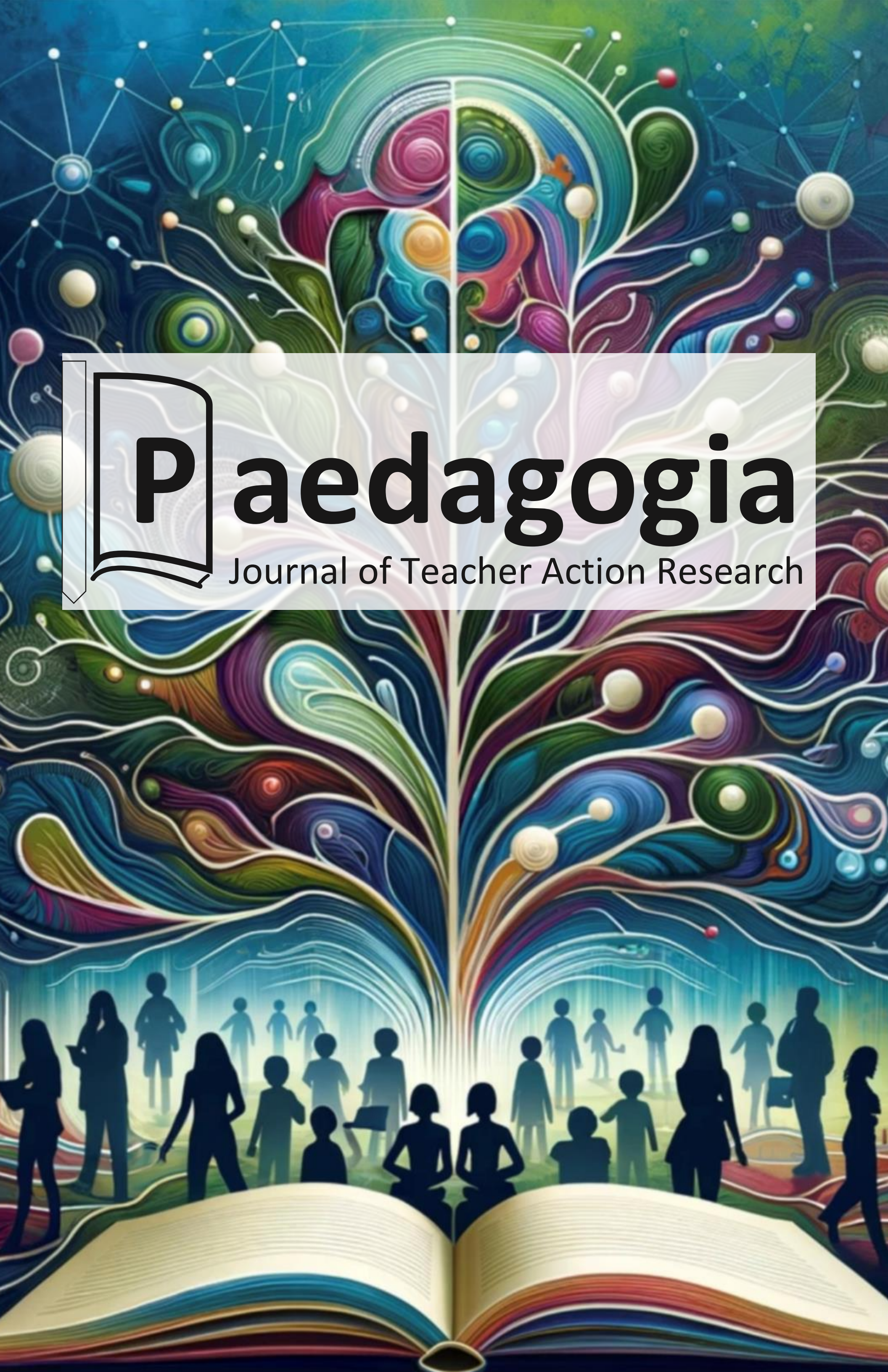

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Which Inquiry-Based Teaching Method is Most Effective in Soliciting Student Interest: Open or Guided?

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This study compares the effectiveness of two inquiry-based (open vs. guided inquiries) science labs in soliciting student interest in science. It explores how student interest can be mediated by the dynamics of shared roles in inquiry-based investigation process by comparing guided labs (where teachers guide the inquiry and students' activities) and open labs (which are almost entirely student directed). The goal is to contribute to the effectiveness of science lab processes, as existing research on the subject presents mixed findings. In this study, 48 high school freshmen participated first in a guided, followed by open laboratories. The overall class interest in science was assessed through Likert Scale surveys. Students took the same survey three times—before engaging in the labs, after the guided lab, and then after the open lab. In addition, the students answered reflective questions comparing both laboratories after both labs. In general, the results of the survey did not reveal any discernable pattern indicating which type of lab increased student interest. However, the reflective responses revealed that, while increases in interest had little to do with the level of teacher to student involvement in the investigative process, they were associated with the topic of the lab being studied. In other words, the topics of the labs reported sparked newfound interest in students that were not initially there prior to engaging in the lab. This has important implications for teachers when deciding what content to investigate in the class.

Keywords: Guided Inquiries, Open Inquiries, Student Interest

Introduction

Science has typically been regarded as one of the subjects that many middle and high school students struggle with. This is because a lot of learning traditionally involved in teaching science is boring to students (Oliveria, et al., 2013; Toolin, 2003). Students also find it difficult to connect science to their personal lives, and therefore, students become disengaged (Toolin, 2003).

In my research, I have found seven key strategies science teachers can apply to improve student interest and consequent achievement. These include using visual aids in lectures, assigning homework in moderation, differentiating, making content relevant to student lives, implementing hands-on, interactive activities, and engaging students in inquiry-based activities (Resnick, 1977; Toolin, 2003; Oliveira, et al., 2013). However, of all the strategies, implementing activities based on inquiry is the most effective in soliciting student interest and learning (Oliveria et al 2013; Toolin 2003).

However, there are three levels of inquiry-based instruction—structured, guided, and open (Zion & Mendelovici 2012; Kang & Keinonen, 2017; Sadeh & Zion, 2011). Structured inquiries do not really cultivate any critical thinking skills and are often reserved for students that have limited experience engaging in scientific investigations (Zion & Mendelovici, 2012; Sadeh & Zion, 2011). Guided and open inquiries are more intended for students with experience engaging in scientific investigations (Zion & Mendelovici, 2012).

Learning led by guided inquiries cultivate better critical thinking skills (Shalihin & Masturi 2019), and conceptual understandings (Almuntasheri & Giles, 2016), compared to learning led by structural inquiries. However, learnings led by open inquiries cultivate the best critical thinking skills (Romadhoma & Suyanto, 2020) and procedural understandings (Sadeh & Zion, 2009) since students independently carry out investigations as actual scientists would.

It would therefore make sense for teachers to implement learning activities primarily based on open inquiries. One of the main problems is that many teachers have trouble implementing such activities in the classroom because they do not have the necessary skills and background knowledge (Arslan, 2014). Additionally, the research I have reviewed presented mixed information about guided and open inquiries.

Some studies indicate that students gained more of an interest in science after engaging in guided inquiries rather than open (Chatterjee, Williamson, McCann & Peck, 2019; Kang & Keinonen, 2017). Other studies indicate the opposite—students gained more of an interest in science after engaging in open inquiries rather than guided (Zion & Sadeh, 2011). Thus, how guided and open inquiry processes shape interest in the subject need further investigation.

Research indicates a strong, positive correlation between subject interest and academic achievement (Chatterjee, Williamson, McCann & Peck, 2019). In other words, students are more likely to learn a subject when their interest in the subject increases. Therefore, if my investigation reveals that open activities lead to a greater increase in interest, compared to guided activities, it might be worthwhile for science teachers to invest time in learning the methods and strategies needed to implement activities based on open inquiry. Similarly, if the students in the guided group reported a greater overall increase in interest, it might be in the best for the teachers to continue implementing activities based on guided inquiry.

This study will involve one group of 48 freshman aged high school students. Students will take a Likert-Scale survey to assess their scientific interest prior to engaging in the labs. Students will then take the same survey after engaging in the guided lab and then once again after engaging in the open lab. The surveys are intended to see if the labs have any effect of increasing interest. After engaging in both projects, students will also answer reflective statements comparing both projects. The reflective statements will be analyzed deductively to determine what aspects of the projects (if any) would have influenced an increase in interest.

Review of Literature

Research points to various strategies science teachers have used to stimulate and sustain students' interest and overall engagement as well as improve their achievement in science. While some seem to work, even the most successful strategies reveal issues of implementation.

Seven Key Strategies for Boosting Science Interest

Among the strategies that seem to enhance student engagement and improve their achievement are (a) using models, diagrams, and other visual aids to classroom lectures, including demonstrations (e.g., hatching butterflies in the classroom to demonstrate metamorphosis) (Resnick, 1977); (b) homework, especially when assigned in moderation (Oliveira, et al., 2013); (c) differentiation, especially the use of peer tutors and in-class translators (Oliveira, et al., 2013); (d) student collaboration to learn specific concepts and to solve common problems (Oliveira, et al., 2013); (e) implementation of hands-on learning activities (Toolin, 2003; Oliveria, et al, 2013); (f) lastly, relevance to student lives in relation to the content being delivered engagement (Oliveria, et al., 2013; Toolin, 2003).

Inquiry as a Best Practice:

Oliveria et al (2013) examined the average student achievement on the Grade 8 state science exam in ten different middle schools in a New York region. Seven of those ten schools consistently performed higher than the state average, and three of the ten schools consistently scored around average. Ten of the schools came from areas of poverty, and the top three performing schools were in one of the lowest areas of poverty in New York. Also, a majority of the students in these schools are minorities, ESL students, and students with disabilities.

Yet, the ten schools listed consistently performed average or higher overall on the state exam. The reason for this is because teachers from these schools consistently implemented the seven key strategies discussed above. In the top three performing schools, teachers most frequently implemented hands-on inquiry-based learning activities. Oliveria et al (2013) concluded that hands-on, inquiry-based learning is one of the best practices science teachers could implement to improve interest and achievement.

Other studies agree with the assertion. Toolin (2003) conducted a study where 18 high school juniors spent a summer working with college professors engaging in science investigations in Suffolk County, New York. Some of the investigations including learning to use GPS navigation to map various points of the shoreline in the area, designing microcosms (fish tank habitats) that were similar to the different aquatic ecosystems in the area, and conducting chemical tests on different soil samples to determine the location of a pollution source. The role of the professors was to pose possible science-related questions that students could explore, and then help the students formulate plans to explore those questions (Toolin, 2003).

After working with the college professors, those same juniors taught similar investigations to middle school students. Although the activities for the middle school students were more structured and pre-determined, in both cases, the professors and then the juniors engaged their students in inquiry-based learning (Toolin, 2003).

Toolin's (2003) study revealed an increased interest. Prior to completing the program, out of the 18 juniors interviewed, only 8 said they were interested in possibly considered a career in the field of science. Of those 8, only 5 said they were interested in pursuing a career in teaching science. However, after completing the program, 14 out of the 18 students now reported an interest in possibly pursuing a career in science, and of the 14, 9 were now interested in pursuing a career teaching science (Toolin, 2003). After completing the program, when asked about what they like most, the students reported engaging in hands-on, inquiry-based activities.

Both Toolin (2003) and Oliveria et al (2013) conclude that hands-on, inquiry-based learning is one of the best practices teachers can implement to increase student interest. Their findings are in line with John Dewey's assertion that students learn more when they are involved in discovering the knowledge, rather than having that knowledge fed to them without context (Noddings, 2016). Dewey suggests an inquiry-based, problem-solving approach to learning. He suggests students explore a question or problem and then propose a hypothesis related to that question or problem. Students then test their hypothesis in an experimental investigation. If the results of the investigation support that hypothesis, students will accept their hypothesis, and that hypothesis becomes knowledge. If the results do not support the hypothesis, students reject the hypothesis, and propose an alternative one to be investigated (Noddings, 2016).

However, as I discuss below, there are three levels on inquiry that exist—structured, guided, and open—each with increasing levels of student independence in learning as one moves from structured to open (Zion & Mendelovici, 2012). Toolin (2003) and Oliveria, et al., (2013) only addressed guided inquiries in their studies. Other research I reviewed indicates different pros and cons for each level.

Three Level of Inquiry – Structured, Guided and Open:

Structured inquiries are the most teacher-oriented in terms of design. The teacher selects a question or problem students will explore, as well as the hypothesis related to that question or problem. The teacher also determines the experimental methods students will use to test their hypothesis. Results from the investigation are also predetermined, and the teacher directs the students on how to interpret the results, and on what conclusions to draw from those results (e.g. if they should accept their initial hypothesis, or propose an alternative one (Zion & Mendelovici, 2012).

Activities based on guided inquiry involve more of a balanced role in teacher-student design. For example, the teacher might still determine the question or problem to be explored, as well as the hypothesis. However, students will determine the methods of investigation. Students will also analyze their own results, and draw their own conclusions (Zion & Mendelovici, 2012).

Open inquiries are the most student-driven, as students assume responsibility for almost everything in the investigation. They select a problem or question to explore that is related to the topic of study as well as the hypothesis related to the question or problem. Students also dictate the methods of investigation, independently interpret the results, and draw their own conclusions. Teachers have very little involvement other than to define the knowledge framework, monitor student progress, and suggest possible alternatives if one hypothesis, or method of investigation does not work (Zion et Mendelovici 2012).

Structured vs. Guided Inquiry:

For students that do not have much experience with scientific investigations, structured inquiries are good introductory activities that introduce students to the ways in which scientists think and investigate problems. They are also ideal for students that struggle to think out of the box (Wilcox, Kruse, & Clough, 2015). However, structured inquiries are not enough for students to develop the critical thinking skills and procedural understandings they would need to pursue a career as a scientist (Zion et Mendelovici 2012).

Research indicates that when compared to structured inquires, guided inquires play more of role in cultivating the critical thinking skills and conceptual understandings students need to pursue careers in science (Shalihin et Masturi 2019; Almuntasheri et Wright 2016).

Shalihin et Masturi (2019) determined that junior high school students engaging in six weeks of guided inquiries developed better critical thinking skills compared to students that engaged in six weeks of structured inquiries. Before the 6-week period, both groups of students were assessed on their overall critical thinking abilities in terms of five areas: (1) their overall ability to identify a problem or question to investigate, from a broader topic, (2) their ability to screen different sources for reliability, (3) their ability to draw conclusions from observations, (4) their ability to identify assumptions from arguments, and (5) their ability to determine an appropriate action to solve a problem.

After the 6-week period, both groups were again evaluated in their overall critical thinking abilities in the five areas noted above. According to the results, students in the guided group gained more significant overall improvements, in four of the five areas of critical thinking—identifying questions, screening sources, drawing conclusions, and identifying assumptions compared to the students in the structured group. The researchers concluded that the only reason this was not the case for the fifth category, determining an appropriate action, is because, in the guided group, the teacher still played more of a role in dictating the methods of investigation for collecting data (Shalihin & Masturi 2019).

Almuntasheri et Wright (2016) also determined that activities based on guided inquiries improved overall conceptual understandings more so than activities based on structural inquiries. In their study, they also compared the overall conceptual understanding of density in two groups—one group that learned about it through structural inquiries, and the other group through guided inquiries. Before beginning the unit, students from both groups were assessed in a pre-test about their understanding of density. Students in the "structured" group then learned about density mainly through lecture and structured inquiries, while students in the guided group learned about it mainly through lecture and guided inquiries.

At the end of the unit, students from both groups were again assessed on their understanding in a post-test. The results indicated that overall, the students in the guided group demonstrated significantly greater improvements in their ability to explain what density is and apply in their ability to solve mathematical problems related to density and volume (Almuntasheri & Wright, 2016). However, some research indicates that open inquiry has the most effect in cultivating critical thinking, as well as instilling the mindsets and procedural skills students need to engage in their own investigations.

Guided vs. Open Inquiry:

Zion & Mendelovici (2012) assert that open inquiries cultivate the most critical thinking skills and procedural knowledge students need to independently carry out their own scientific investigations. Other studies support this position. For example, Romadhona & Suyanto (2020) conducted a study on 10th grade biology students, in Yogyakarta, Indonesia. In their study, one group of 30 students received instruction based on open inquiries, and another group of 30 students received instruction on guided inquiries. Students from both groups received a pre- and post-test that assessed four elements of integrated science process skills—planning an experiment to test a hypothesis, carrying out the investigative procedures of the experiment, analyzing the results of the experiment, and communicating the conclusions drawn from those results (Romadhoma & Suyanto, 2020).

The pre-test administered before the treatment examined the students' knowledge of the four steps, while the post-test examined the students' ability to apply the four skills. Initially, the average score for the pre-test was higher in the guided inquiry group. However, the post-test revealed that students in the open inquiry group scored significantly higher in all four categories than the guided inquiry group (Romadhoma & Suyanto, 2020). The results indicate that open inquiries better cultivate the critical thinking skills students need to problem solve to carry out their own investigations.

Sadeh & Zion (2009) also conducted a similar pre- and post-test assessment on two groups of students and determined that students that spent two years learning from activities based open inquires demonstrated better overall flexibility and procedural knowledge, compared to the students that spent two years learning by activities based on guided inquiries.

Flexibility was measured in terms of adapting to changes that occur in the research process such as changing hypotheses and/or data collection methods in response to new findings in the investigation. Similarly, students in the open group demonstrated better overall procedural understandings—in terms of a better ability to select an appropriate data collection method, based on the nature of an experiment, and in terms of selecting a specific type of statistical analysis, appropriate for the type of data collected in the experiment (Sadeh & Zion, 2009).

Problems with Implementing Open Inquiries:

Since open inquires best cultivate the procedural knowledge and critical thinking skills students need to pursue investigations independently, it would seem logical that teachers try and include open inquiries in the curriculum to the maximum extent possible. However, this is not always as simple as it sounds. Firstly, many students can become frustrated by the time-consuming process of trying to determine relevant questions and problems that can be considered for investigation (Zion & Mendelovici 2012; Wilcox, Kruse, & Clough, 2015). It is also rare for most high school aged students to independently pose valid questions and hypotheses that can be investigated, as well as to independently design valid experiments to investigate their questions and hypotheses. In most cases, teachers must provide scaffolding for students to suggest valid questions and reasonable experiments, which is a defining characteristic of guided inquiry (Wilcox, Kruse, & Clough, 2015).

Teachers also experience difficulties in successfully implementing activities that involve open inquiry. Arslan (2014) determined this is because most general education teachers also are not able to generate valid questions and hypotheses for investigation. In cases where teachers can generate valid questions and hypotheses, they often struggle in designing their own experiments. This is because most teachers, when delivering the curriculum, are given a pre-determined hypothesis for investigation, as well as a pre-determined design for an experiment that will test the hypothesis. If the teachers cannot generate their own questions and experiments, they certainly cannot help their students create questions and experiments either. As a result, most general teachers resort to activities based on guided inquiries (Arslan, 2014).

Zion & Mendelovici (2012) propose a model to counter both predicaments. In the first case, students become accustomed to engaging in open inquiries by gradually transitioning from structured, to guided, to open inquiries. By the time students reach open inquires, students will have the experience necessary to generate their own ideas for questions and experiments.

In the second case, general teachers receive additional training to help formulate valid questions and experimental investigations. Teachers also receive training in assisting students in designing their own ideas. Schools in Israel have adopted this type of model to support the implementation of open-based inquiries. However, no such model exists in American schools (Zion & Mendelovici, 2012).

Conflicting Findings:

Of primary importance to this research is determining what method of inquiry cultivates the most student interest in science. Research indicates a strong positive correlation between subject interest and academic motivation and achievement. In the case of science, students are more likely to learn the conceptual material and engage in investigations when they are interested the material and investigations. Instilling an interest takes precedence over cultivating critical thinking skills and procedural knowledge, because if students are not interested in the material, they certainly will not want to engage with it. This is also in line with Dewey's educational philosophy. Dewey (1910) mentions how any experience in the classroom must also open doors to the possibility of the student engaging in a variety of new, different experiences. In order for that to happen, the experience itself must be interesting and enjoyable to the student at the moment it happens. Experiences that are not interesting and/or enjoyable to the student are not educative because these experiences will create a reluctance to engage in future, similar experiences. Therefore, teachers should choose to implement the method of inquiry that instills the most student interest.

The problem is that research indicates mixed results about what is the best method of inquiry to implement. For example, Kang & Keinonen (2017) collected data on 4714 Finnish students from 155 different schools. Each school was assessed for the primary instruction method the teacher applied in the classroom. The overall student interest and achievement in each school was also assessed to determine if there was a correlation between instructional method and overall interest and achievement.

The results indicated that an emphasis on guided inquiry was positively correlated with increased interest, and overall performance. However, open inquiry was correlated with a decrease in interest and overall performance. The researchers mention "that when students are involved in conducting and concluding the investigation, rather than in designing or asking their own questions, they present clearly better academic achievement (Kang & Keinonen, pg. 880)."

Chatterjee, et al., (2009) conducted a similar study that assessed overall student opinion in laboratories that emphasized open and guided inquires. About 703 students were considered in the study, and all students engaged in laboratories that emphasize both open and guided investigations. The results of the study indicate that the majority of the students (81%) reported having more of an interest in the guided inquiries compared to the open inquiries. In addition, the majority of the students (65%) also reported learning more from the guided inquiries, compared to the open inquiries (Chatterjee, et al., 2009).

However, other studies indicate inconsistent findings. Sadeh & Zion (2011) also engaged in a study where they assessed the opinions of Israeli students, after the students had engaged in different inquiry-based projects. One group of students participated in open inquiries and another in guided inquiries. Overall opinions were assessed after the activities were completed.

Results indicated that students engaging in the open inquiries were more satisfied with the project, and felt they gained benefits to a greater extent, compared to the students engaging in guided inquiries (Sadeh & Zion 2011). More specifically, the open inquiry students "expressed a greater motivation and interest in science, a greater sense of cooperation in working with other peers, and a development of abilities to work autonomously in designing and conducting various experiments, and interpreting the results (Sadeh et Zion 2011, pg 844)."

The last three studies I discussed indicate contradictory findings. The research from Kang & Keinonen (2017), and Chatterjee, et al., (2019) indicate that guided inquiries lead to an overall increase in student interest in science. However, the results from Sadeh and Zion (2011) indicated that open inquires lead to an overall increase in student interest. With my study, hopefully it will become easier to determine what methods of inquiry lead to greater student interest in studying science and possibly pursuing it as a career.

Methodology

This study's sample consisted of forty-eight freshman aged students (14–15-year-olds). Twenty-five of those students were in the first block, and twenty-three of those students were in the second block. However, data from both groups were combined. As mentioned earlier, the purpose of this study was to determine which type of lab solicited an increase in interest in science—open or guided. Therefore, to determine this, students took a Likert-Scale survey prior to engaging in the labs. The survey has questions that are loosely based on questionnaires done in previous studies designed to assess interest in science.

Students then took the same survey again after completing the guided lab and then once again after completing the open lab. All forty-eight students responded to the survey each time. The total number of responses (on the scale 1-5) were counted each time for every question to see if the labs were soliciting an increase in interest. In addition, after completing both the open and the guided labs, students answered seven reflective questions comparing the different lab. The reflective questions were deductively coded according to three general categories—preference, collaboration, and interest solicitation.

In both labs, students were broken up into groups of four to five. In the guided lab, each group was given the following hypothesis to investigate – does nitrogen-based fertilizer improve growth in aquatic and terrestrial plants? Students were also given instructions to build two terrariums. One terrarium would consistently expose both terrestrial (10 Wisconsin Fast Plant Seeds) and aquatic plants (Elodea bulbs) to water mixed with nitrogen-based fertilizer, while the other would only expose the plants to regular water (see figure 4 for more details on the lab design). Students were given the hypothesis, and the instructions for designing the lab. However, as characteristic of guided labs, they were in charge of deciding what type of data they would collect, ensuring that the data was collected for all four data collection periods. Students were also in charge of analyzing the data and drawing conclusions.

Students began constructing their plant labs on March 30, 2022. Data for the plant lab was also collected over periods – March 30, April 1, April 5, and April 7 of 2022. In the fourth period, students also discussed how they would write up the laboratory (see figure 4 for rubric). Students turned in their lab reports a week later, April 14) (see figure 5 for a sample lab report).

On April 7, students filled out the survey a second time and began constructing their cricket terrariums for the open lab (see figure 6 for directions and rubric). Characteristic of an open lab, I only defined the knowledge framework the students would work from, which was designing a survivable habitat for house crickets. I also provided the actual crickets and 2-Liter bottles that students would construct their habitats with. However, students were in charge of determining how they would build their habitats, determining what food and materials they would need to keep their crickets alive.

On April 7, students worked in their groups to research a habitat design, and materials they would need to keep the crickets alive. I created a worksheet with a potential habitat design and with prompts to help students think of what materials they would need to keep the crickets alive (see figure 6). The following Monday, April 11 students brought their materials in, and began constructing their habitat.

Data collection also started on this day. Data collection consisted of counting the number of crickets that were alive after every observation. Each group started with seven crickets, and if at any point crickets were seen dead or dying, students needed to adjust their habitats. For example, in one group, the students added too much moist soil to their habitat, and this resulted in mold growing in their habitat. Consequently, several crickets died, and the students then decided to change their substrate from soil to sand (which holds less moisture). Some students also designed unique ways to keep the water all in one place in the habitat by putting it in a cap inside the bottle.

Data collection for this lab took place during April 11, April 14, and April 19. Because my mentor teacher did not want to pursue the lab anymore after the 19, I could only complete three data collection periods with the class. On April 19, students made their last counts for how many crickets were in the terrarium and then what changes they would have made to the habitat, if they were to continue this lab further. Students also completed the survey a third time and were given a rubric for the cricket lab write up due on April 25 (see figure 6 for rubric, figure 7 for sample lab write up). Lastly, on this day, each student responded to a reflective statement comparing both labs.

Results

Part 1: Survey Responses

As mentioned earlier, forty-eight students took the same survey assessing interest in science, three different times. All three times, I counted the total student scaled responses to each survey question. Prior to engaging in the labs, the total number of student responses were as follows (see figure 1):

Bar Graph of 1st Survey Responses, Prior to Engaging in Labs

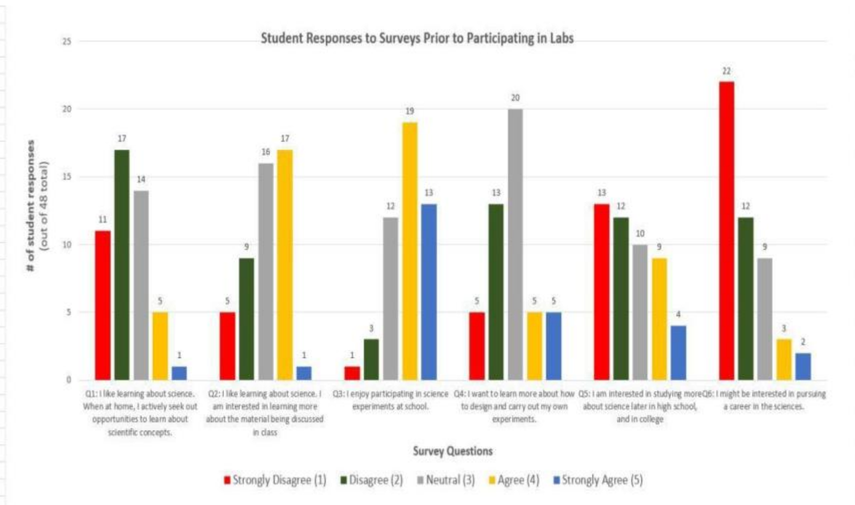

Figure 1: The bar graph above shows the total number of student responses to each question, prior to engaging in the labs. The x-axis represents each question (1-6) on the survey, as well as the scaled possible responses. For each response, red corresponds with strongly disagree, green corresponds with disagree, gray corresponds with neutral, yellow corresponds with agree, and blue corresponds with strongly agree. The Y-axis corresponds shows how many students responded a particular way to each of the six questions.

After engaging in the guided lab, the total number of responses to each survey question were as follows (see figure 2):

Bar Graph of 2nd Survey Student Responses After Engaging in Guided Lab

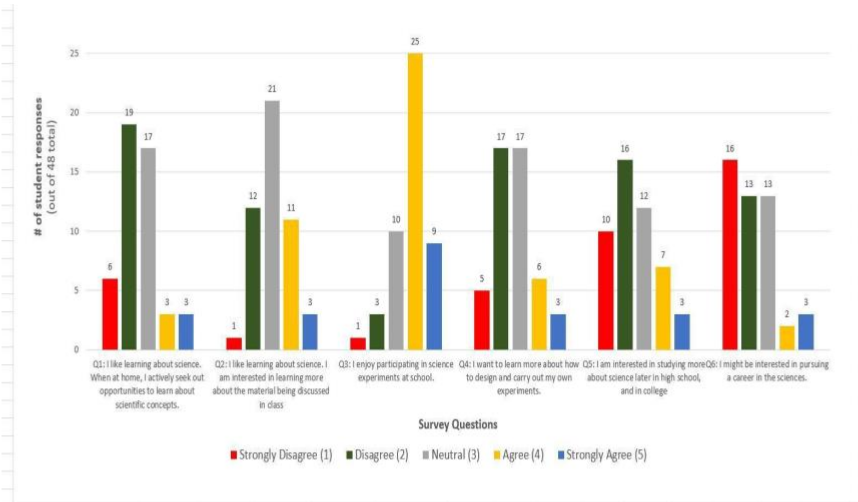

Figure 2: The graph above shows the number of student responses for each question on the survey after engaging in the guided lab.

After engaging in the open lab, the total number of responses to each survey question were as follows (see figure 3):

Bar Graph of 3rd Survey Student Responses, After Engaging in the Open Lab

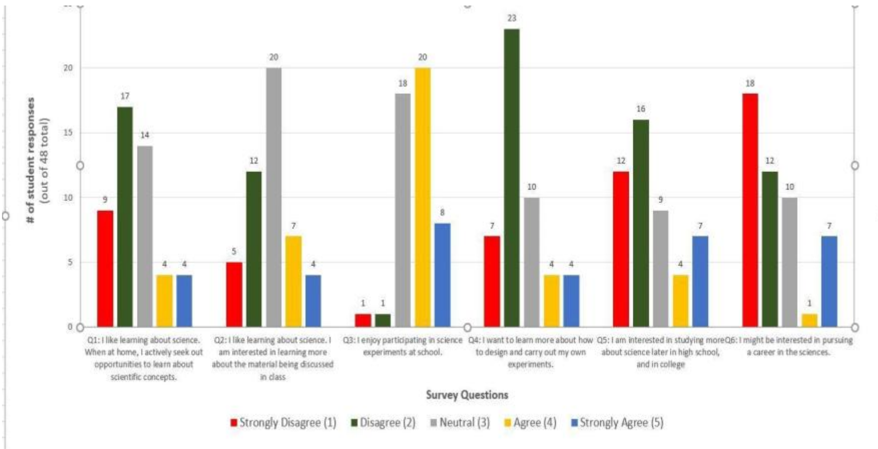

Figure 3: The graph above shows the number of student responses for each question on the survey after engaging in the open lab.

In general, the total responses for most questions only vary by a marginal amount after each survey. For example, with survey question 1, after the first survey, the responses were 11, 17, 14, 5 and 1, for strongly disagree to strongly agree, respectively. After the second survey, the responses for question 1 were 6, 19, 17, 3, 3, for strongly disagree to strongly agree, respectively. After the third survey, the responses for question 1 were 9, 17, 14, 4, and 4, for strongly disagree to strongly agree, respectively.

Thus, for question 1, the total number of students on the "agree side: (circled "agree" or "strongly agree") was 6, 6, 8 and the total number on the disagree side (circled "disagree" or "strongly disagree") was 28, 25, and 26, after the first, second, and third survey, respectively.

A similar pattern can be seen in other questions, where the total number of students on the agree or disagree side does not differ that much after each survey administration. For example, with regard to question 5, the total number of students on the agree side are 13, 10, and 11, and the total on the disagree side are 25, 26, and 28, after the first, second, and third survey administration. The same is the case for the neutral category. For the most part, the total number of students that responded with a "neutral" for each question only varies by a marginal between survey 1, 2 and 3.

In addition to that, some of the results are the exact opposite of what I expected. For example, with regard to the fourth question, 5 and 13 students circled "strongly disagree," and "disagree," respectively, after the first survey, 5 and 17, circled "strongly disagree," and "disagree," respectively after the second survey, and 7 and 23 circled "strongly disagree" and "disagree," respectively, after the third survey. This means that 18 total (38%) were on the disagree side, after the first survey, 22 (45%) after the second survey, and 30 (62%) after the third survey. Also, for that same question, the total number of students on the agree side, gradually decreased from 10, to 9 to 8, after the first, second and third survey.

I would have expected the exact opposite—that fewer students would be on the disagreement side, and more on the agree side, after each administration. Most research suggests that both open and guided labs should have the effect of increasing student interest in designing and conducting their own experiments. But that is not what I observed. The same pattern is evident in question 2. The total number of students on the agree side is 18, 14, and 11, and 13, 14, and 17 on the disagree side, side after first, second and third survey, respectively.

Lastly, there are no evident observable patterns that would indicate these labs have a significant effect in increasing student interest in science. In other words, if it was determined from the survey that the guided (and/or open) labs had a significant effect in increasing interest, you would expect to see a significantly greater amount of the students on the agree side and significantly less amount of students on the disagree side, after survey 2 (and/or survey 3), compared to survey 1. However, upon analyzing the survey responses, it is apparent that this is not the case with any of the questions.

In most cases, the total number of students on the agree or disagree side fluctuates inconsistently. As in the case with question 3, where after survey 1, 2, and 3, the total number of students on the agree side is 32, 34, and 28, and the total amount on the disagree side is 4, 2, 3, respectively. Also, in some cases, after survey 1, 2, and 3, the number of students on one side may gradually increase or decrease (by a small amount) but fluctuate inconsistently on the other side. The only times there is a notice pattern on both sides, is in the responses to question 2 and 4, and in both those cases, the pattern contradicts what current research claims is true. While it is possible the labs themselves may have influenced these specific questions (question 2 and 4), it is more likely a result of chance. It is possible that the survey failed to adequately assess interest, and I will explore this in the Discussion section of the paper.

Part II: Reflections

In the second part of this study, students answered reflective questions after engaging in both labs. As mentioned earlier, the methodology of this study involved inductive coding – having a set of broader themes in mind that have been assessed in previous similar studies. The three broader themes I searched for in student reflective responses were preference, collaboration, and interest solicitation. In terms of preference, the results were mixed. Some students did report being more comfortable with the structure and guidance of the plant lab, rather than the open ended-ness of the cricket lab. For example, one student reported: "I personally liked the structure of the plant lab better, because it was easier to do with the structure." Another student reported a similar sentiment saying, "I enjoyed having structure because it made it easier to record data and make a conclusion."

However, more of the students reported enjoying the cricket lab more because they felt a greater sense of responsibility, experienced more creativity and freedom, and felt a greater collaboration with peers. For example, one student specifically said, "I liked the cricket lab, because I felt more responsibility when being in charge of designing and maintaining a habitat that will keep the crickets alive." This sentiment is in line with recent research. Dorfman et al,

(2020) determined that students who engaged in open inquiries generally reported feeling more personal responsibility for the procedural process of scientific investigations. These students also felt a greater importance for the investigation. In comparison, most students involved in the guided labs reported felt that engaging investigative was merely part of the demands imposed by the teacher, without truly its importance.

Along the lines of freedom and creativity, one student said, “I like the cricket more because I liked having more freedom that allowed me to design the habitat.” Another student echoed the sentiment and said “I didn’t enjoy the structure of the plant lab because it’s designed to be a successful ecosystem, while I enjoyed the cricket lab because you must learn on your own what works and what doesn’t. That helps me learn better.” Lastly, one student reported preferring the cricket lab because, “I enjoyed more freedom because it allows us to show creativity. It was also more fun, because everyone had a unique design.”

Almost all students felt a greater sense of collaboration in the cricket lab, particularly when designing the habitat discussing the materials, they would need to design the habitat. For example, one student specifically said, “I felt more collaboration with the cricket lab, because we all had to agree upon a suitable habitat and work together to determine the materials that would create a suitable habitat.”

When responding to collaboration, another student said, “The cricket lab for sure, because we all contributed to making the home”. Lastly, in terms of soliciting interest, most students responded with “no” when asked specifically if any of these projects made them more interested in pursuing their own investigations, and/or in continuing to work in science as a career. Students either responded, “I am not interested in science, and this didn’t change how I feel” or “I was already interested in science, and this didn’t really change much.”

For the students that did express an increase in interest in the reflective statements, I did not get a sense that increase in interest had anything to with the semi-guided or open-ended aspect of the projects. Instead, students expressed interest in science because of the specific topics they were studying. For example, one student mentioned how the cricket lab made him want to learn more about what type of habitats insects need. He explicitly stated, “I would like to design habitats for other insects around my house.” Another student said, “the cricket lab made it so if I were to pursue my own experiments, I would use insects.” And from the plant lab, a couple students expressed a newfound interest in learning about how to grow their own plants at home. One student even said, “the plant lab made me more interested.” “This is because myself curious about how things grow at such rapid speeds.”

When asked if students were specifically if any of these projects increased their likelihood of continuing to study science, and possibly pursue it, most indicated that the projects did not have an effect in influencing their decision. Again, most students stated that science was “not really their thing.” However, as mentioned above, some students indicated the projects did incite an interest in specific topics related to science, such as insect care and plant growth. One student even suggested that the projects incited an interest in a broader conceptual field. She specifically stated, “I am not very interested in science as a career or a hobby outside of school. However, these projects do make me wonder how the outside world works, which is kind of trippy.”

Discussion and Limitations

In theory, the surveys should have been effective in assessing if the projects solicited an increase in interest. As mentioned earlier, the questions are loosely based on questions used in other studies. However, there are three reasons I do not think they worked. First, the students were also already familiar with the survey, and it had not been very long between the time the students took the first, second, and third survey. This was because of the time constraint imposed on both labs. In order to get through the regular school curriculum, I could only commit three weeks to implementing both the open and guided lab.

Due to the time constraints and being already familiar with the survey, students may have answered the survey the same way they did the second, or third time around, even if a particular project might have increased their interest in science. In addition, some of the students in the group may have answered the surveys in such a way that they thought would make me happy, rather than in such a way that may have reflected their actual opinion. For example, one student circled all "5s" and said, "look at this Mr. Frederick." Having my validation too might have influenced the results of the survey.

Moreover, because both labs were limited by time, I do not think I could fully assess if having more guidance or open-endedness plays a role in soliciting more interest in science. If I had more time, I may have been able to do this. Although the problem was that I should have issued the reflective statements after the students had finished their cricket lab reports. I issued the reflective statements before the cricket lab report was due, due to time constraints, and not being allowed to dedicate any more time to the lab. If I had done it after, I probably would have obtained somewhat more detailed responses to the cricket lab on the reflective statements.

However, with the reflective surveys, I was still able to affirm some of the sentiments expressed in other studies—namely that many students prefer open ended labs, because such labs promote creativity and freedom. I was also able to affirm that the open-ended labs promote a greater sense of collaboration, because student are more involved in a discussion when deciding on a design.

For the students that did express a potential increase in science, it was likely because they already had an interest in the topic being studied, or the lab may have sparked a newfound interest the student may not have already had. For example, as I stated in the results, some students indicated they were interested in learning about the different habitats insects need after engaging in the cricket lab. Others indicated they were interested in learning how to grow their own plants after engaging in the plant lab. This has important implications for teachers when they are choosing topics to be studied in the lab. Students are naturally more likely to continue studying a topic if they are interested in the topic. It therefore becomes the teacher's responsibility to choose topics he or she feels her students might be interested in.

Future Studies

I think it would be a good idea to repeat this study when there are not short time constraints, and the labs can be pursued for longer periods of time. Unfortunately, because high school science curriculum requires a vast amount of information that teachers and students need to cover, I could only dedicate three weeks to both the open and guided lab. In many of the other studies that assessed interest in open or guided labs, the actual labs themselves were carried out for months or even years at a time.

By allowing for more time, the students would be more immersed in the experience, and have more things to reflect on. I would have also likely obtained survey results that more accurately reflected patterns and trends, and deeper insights on the reflective statements. Many of the surveys I read only consisted of one- or two-word responses to different questions without much reflection. That is why I would recommend repeating this study, but with labs that last a longer period.

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Figure 4:
Guided Lab Directions and Problem Statement
Rubric for Lab Report Write Up

Direction for Today:

- Put Initials of members in group on terra-columns
- Mark whether your bottle had nitrogen in it or not
- Put Class Block Number on Bottle.
- Sticky Notes will be provided

Guided Lab Question: Does nitrogen based fertilizer improve growth for land and aquatic plants?

Hypothesis:

Experimental Plan:

Data Collection:

- Day 1:
- Day 2:
- Day 3:
- Day 4:

Guided By Questions: Does nitrogen-based fertilizer improve growth for land and aquatic plants?

Materials

1. Ruler
2. String
3. Sharpies
4. Two 2-Liter Bottles
5. Waterproof Clear Tape
6. Scissors
7. Fabric Sheet
8. 300 ML Beaker
9. Garden Soil

10. Wisconsin Fast Plant Seeds
11. Green Moss plants or Edible Plants

Directions for Building Tarra Aqua Columns

1. Each group is building 2 Terra Aqua columns; therefore, each group needs two bottles.
2. With a sharpie, make a mark on the bottle 9 cm down from bottle top.
3. With string, draw a circle around your mark. Use a sharpie to make a circle.
4. Cut out your circle - therefore cut the top off the bottle, making two pieces (part A and B).
5. Use your poker/screwdriver to punch 10 holes around the diameter of Part B - 3 inches from the cut line.
6. Use a screwdriver to punch a hole in the cap of the bottle.
7. Thread your 20 cm piece of fabric through the cap of the bottle, make it so that (10 cm) is through both sides of the cap.
8. Re-attach cap with thread to part A.
9. Add aquatic plants to the bottom of bottle B.
10. Add 600 ml of water to both bottles B.
11. Add one tablespoon of nitrogen-based fertilizer to one of the bottles B.
12. Add the top of A to B as shown in the diagram.
13. Tape A to B at the sides. Tape the very end of the piece of fabric to the A-B edges.
14. Add soil to A.
15. Add seeds to soil in A, then water well.

Rubric for Plant Lab

1. Each group must turn in one lab report of the plant project.
2. Every group member must contribute to the report.
3. Members in a group can work on different sections. However, each member must contribute.
4. Lab report is due one week from when it is assigned (April 14th).

Name, Date, Title, Conventions (2 pts):

Students will include in the report…

1. All group member first and last names
2. The date the class started the experiment
3. Adescriptive title capturing on their report, that accurately captures the purpose of the lab.
4. The attached handout with the hypothesis, experiment design, and data collection.
5. Lab is appropriately formatted with a title, introduction, materials and methods, results, and conclusion/discussion section.

Introduction (3 pts):

Students must include a brief introductory paragraph. This paragraph must include the following…

1. A brief rationale stating the purpose of this lab. The purpose will be in the problem statement of this lab (found on the data collection sheet of lab)
2. A summary of their predications. Students will briefly mention what they hypothesized would happen to both the aquatic and terrestrial plants in the nitrogen conditions, and without the nitrogen conditions. Students will justify their predications, based on what they know about diffusion and osmosis.

Materials and Methods (5 points)

Students must include a methods section that includes the following…

1. A list of materials used in the experiment. This can be a list of bullet points, and the materials can be found from the data collection handout.
2. The methods of the lab. This will include the following:
    a. A brief description of the two terrariums we built (3-4 sentences will be sufficient).
    b. A brief description of the experimental design, which includes
        i. A mention of which terrarium was the control (non-nitrogen), and which was the experimental (nitrogen).
        ii. How data was collected over a period of time days for both the aquatic and terrestrial plants.

Results/observations (5 points):

Students must include an observation and result section that includes the following...

1. A brief summary of their results, for both the terrestrial and aquatic plant measurements.
2. A data for the terrestrial plants, observed on Day 1-4.
    a. If your data consisted of measuring each plant, you would do a table with the measurement of each plant on Day 1, 2, 3, 4

   b. If your data consisted of simply counting the number of plants, you would make a table with the number of plants counted on day 1, 2, 3, 4
   c. Tables can be done electronically, or drawn out by hand, and then attached to overall labreport.
3. A picture of the aquatic plants on day 1 (at the beginning of the experiment, and on day 4, at the very end). Pictures can be uploaded to the lab report.

Discussion/Conclusions (5 points):
Students must include a conclusions and discussion section that include the following…

1. A paragraph that includes a restatement of the lab purpose, a general summary of the results, and a mention of whether or not the results support the initial hypotheses.
2. A paragraph with the scientific principles justifying the results of the lab. In other words, students will discuss why the nitrogen might have improvement growth in both the aquatic and terrestrial plants, if this is applicable.
3. A paragraph discussing limitations to the experiment. Students will describe some technical and procedural errors that might have skewed the results of the lab.

Total Points: 20

Your score

Figure 5
Sample Plant Lab

Plant Lab: Group 1

Names: Sofia, Lily, Maya, Marianna, Adrian, and Min

Introduction:
The purpose of this lab was to see if the use of nitrogen based fertilizer impacted plant growth. We hypothesized that the nitrogen based fertilizer will improve the growth for land and aquatic plants, due to it being a necessary element for the plants to grow better.

Materials and Methods:

Materials
- Ruler
- String
- Sharpies
- Two 2-liter bottles
- Waterproof clear tape
- Scissors
- Fabric sheet
- 300 ML beaker
- Garden Soil
- WIsconsin Fast Plant Seeds
- Green Moss plants or Edola Plants

Methods:
We had two 2-liter bottles, where we cut the bottle 9 cm down from the bottle top. Then we filled both bottles with 600mL of water and put green moss plants in the bottom. We then flipped the part we cut off upside down and taped it. Next we had to add soil with all of the seeds. We then repeated all of these steps with the second bottle, but we added the nitrogen fertilizer.

To keep track of the plants every day we counted the amount of leaves that were grown in total of all the plants in each bottle. During day 1 there were no plants in either terrarium. On day 2, the bottle with the nitrogen had 7 plants and the bottle with no nitrogen had 2 plants. During day 3, the non-nitrogen plants had 4 leaves and the nitrogen plants had 24 leaves. Lastly, day 4 the nitrogen plants had 29 leaves and the non-nitrogen plants had 4 leaves again. We realized that the plants grow better with the nitrogen fertilizer.

Results/Observations: We had pretty good results with both plants. Both kinds of plants were able to grow, but the ones with nitrogen-based fertilizer grew better than the ones without nitrogen. The plants in the one with nitrogen-based fertilizer were able to grow 30 leaves, and the one without nitrogen fertilizer grew a total of 5 leaves.

Number of leaves on plants each day:

Day	Nitrogen Fertilizer	No Nitrogen Fertilizer
Day 1	No Growth	No Growth
Day 2	12 Leaves	2 Leaves
Day 3	24 Leaves	5 Leaves
Day 4	30 Leaves	5 Leaves

Aquatic plants: We did not notice any kind of growth with the aquatic plants.

Discussion/Conclusions:

The purpose of this lab was to see how nitrogen-based fertilizer affects plant growth. We had one terrarium with nitrogen-based fertilized soil and one with just regular soil. On the first day (Day 1), we recorded there were no plants and on the last day (Day 4), at the end of the experiment, there were 30 leaves in the terrarium with nitrogen-based fertilizer and only 5 leaves in the terrarium with regular soil. Our initial hypothesis was correct because we predicted that the nitrogen fertilizer would improve plant growth, and we can prove this was true because of the huge difference between both terrariums. Nitrogen is a component of chlorophyll, which gives plants its green color and creates "food" or energy for plants. This allows the plants to capture energy through sunlight in photosynthesis, helping them grow. Nitrogen can help improve growth in terrestrial plants and aquatic plants because plants need sunlight or energy in order to grow, and nitrogen helps with that. Nitrogen overall speeds up photosynthesis, helping both terrestrial and aquatic plants grow faster and healthier. Our group didn't make any crucial mistakes during this lab that would've affected any of the data we collected, except maybe miscounting the amount of leaves in each terrarium, but the large difference between them still proves that nitrogen-based fertilizer does in fact help plant growth.

Figure 6:
Cricket lab Instructions and Rubric

Open Lab: Designing Homes for House Crickets.

Materials
1. Ruler
2. String
3. Sharpies
4. One 1-Liter Bottles
5. Scissors
6. Poker
7. Sticky Notes

Directions for Today.

1. Each group gets one "1-liter bottle". Cut your bottle 9 cm from the top – Like you did with the guided Plant Lab.

2. Poke 10-20 holes in your bottle – 3 cm from the cut line – this will serve as a flow for oxygen inside and outside the bottle.

3. We will seal up the bottle with Saran wrap the following day.

4. In your bottle, you will be designing a habitat for 10 house crickets *(Acheta domesticus)*.

5. With your group members, create a list of materials you will need to create a survivable habitat for your 10 crickets. Think about the follow prompts when creating your list. Decide amongst each other who will bring which items.

    a. **Food** – What do these crickets eat? How will I satisfy their dietary needs?

    b. **Water** – How will I get water in the terrarium, and keep it inside there?

    c. **Shelter** – Where do these crickets normally live? What can I bring to simulate their natural habitat?

    d. **Surface Area** – The bottle is relatively small? What can I bring to increase the surface area habitat inside the bottle?

6. **Your List**:

7. Data Collection Question – How will you collect data to determine overtime if your habitat is successful in keeping the crickets alive?

Rubric for Reflective Essay

Directions

1. Each group must submit an essay (not lab) report on their cricket project.
2. Every member must contribute to a section, but each group will be submitted a group report
3. Reports will be due April 25rd.

Rubric

Paragraph 1 (5 points): **Purpose, Materials, and Data Collection Procedures**:

1. Need to discuss the Purpose of the lab (1-2 sentences)
2. Need to discuss the materials, food, and method of water retention that were used in your habitat (1-2 sentences).
3. Need to discuss the data collection procedure for determining if your habitat was successful (1-2 sentences).

Paragraph 2 (5 points): **What went well**

1. Need to discuss all the factors that you think aided in the survival of the crickets (1-2sentences).
2. Need to discuss why you think these factors aided in the survival of these crickets (1-2sentences).

*Paragraph 3 (*5 points): **What did not go well**.

1. Need to discuss the factors that limited the survival of the crickets (1-2 sentences)
2. Need to discuss why you think these factors limited the survival of the crickets (1-2 sentences).

Paragraph 4 (5 points): **What Changes did you Make?**

1. Need to discusses the changes you made in adjusting the contents of the habitat in order to enhance the survival of the crickets (1-2 sentences).
2. Need to discuss how the different changes would have improved the survival of the crickets.

Paragraph 5 (5 points): **What would you have done differently?**

1. Need to discuss what you would have done, in retrospect, in terms of habitat design, to make the habitat more suitable for the crickets survival (3-4 sentences).

Figure 7: Cricket Lab Example

Rubric

Paragraph 1 (5 points): **Purpose, Materials, and Data Collection Procedures**

The purpose of this lab was to build a home for 7 crickets and try to keep them alive. As a group we brainstormed and figured out which materials we would need for our crickets to survive.

Materials:

- Ruler
- String
- Sharpies
- One 1-liter bottle
- Scissors
- Poker
- Sticky notes
- fruits/vegetables

The fruit we used was strawberries and grapes, we also used carrots. Our method to getting the crickets water was filling up the lid of the 1-liter bottle with water and using it as a water bowl. The way we determined if our habitat was good was to see if the crickets survived. After collecting data after multiple days, all 7 stayed alive for the first couple days. Then by the end we only had 4 crickets. I would say our habitat wasn't a failure but it did not fully succeed.

Paragraph 2 (5 points): **What went well**

I think that the variety of food aided in the survival of the crickets. I also think that checking our lab everyday helped us in seeing how we could change our lab to further benefit the species. The large variety of food helped the survival because some of the food, such as the strawberries, molded, which left the crickets with some other fruits and vegetables at the end. As I said before, checking up on the lab daily helped us look for areas to improve.

*Paragraph 3 (*5 points): **What did not go well**.

1. A negative factor was that the fruit got moldy after a day being in the habitat. Having moldy fruit is not good for the crickets to eat and it is not good for their habitat environment. Eating the fruit or eating the mold can make the crickets die which is not good. This limited the survival for the crickets because they had no healthy food to eat.

They could die from either starvation or from eating mold. That is not a good situation for the crickets.

Paragraph 4: What Changes Did You Make?

We used strawberries as our source of food for the crickets and, after a couple of days, they started molding, so we replaced them with new strawberries. Another change we made was clearing up the area in the terrarium to make sure it wasn't too crowded, so the crickets would have space to roam, making it more 'life-like'. When we first made the terrarium, we filled it with a lot of food, but crickets don't eat a lot, so we concluded we could take some of that food out and clear up the area. These changes improved survival because, by replacing the food, it ensured that the crickets would have fresh food to eat and wouldn't risk getting sick from eating mold since it can have negative effects on them.

Another change, which was creating more space for them, improved their survival because it made space for them to roam and not feel like they're suffocating.

Paragraph 5: What Would You Have Done Differently?

A few things we could have done differently were to substitute the soil with sand instead because the moisture from the soil was too moist and so the food molded a lot faster. Another thing we could have done was put less food so that there wasn't that much mold. With less food, we could have counted the crickets a lot easier as well.

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