PROCESS ORIENTED GUIDED INQUIRY LEARNING (POGIL)

IN HIGH SCHOOL BIOLOGY

by

Derek Alan Chase

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ABSTRACT

The study investigated the efficacy of Process Oriented Guided Inquiry Learning (POGIL) in a high school biology class when compared to a traditional teacher centered lecture approach. Data was collected through biology assessments, questionnaires, interviews, and class observations. Two classes participated as both the treatment and comparison group for two units each. Results suggest that POGIL is an effective teaching approach when implemented correctly that can improve student performance, increase class engagement, and foster positive attitudes towards learning biology.

INTRODUCTION AND BACKGROUND

I work at University Christian High School, which is located in Hickory, North Carolina. Our school is a small private Christian school where we try to develop our students in terms of their academic achievement, moral character, and servant leadership. This summarizes both our school and class culture. There are 115 students in our school, and the classes I selected for my action research project are my honors biology classes that consist mostly of freshmen and sophomore students. In terms of ethnic diversity, 94% of the students are Caucasian, 4% Asian, and 1% African American (Jerry Willard, personal communication, January 4, 2016). The students at our school needed to reach certain scores on academic tests such as reading, writing, and mathematics, be interviewed by staff members and have letters of recommendation to be accepted at University Christian High School. The ability of the students varies but most do well in honors level courses. Classroom management in terms of student behavior is minimal as many of the students are motivated to learn.

One teaching strategy that I often use in my biology classes is referred to as Process Oriented Guided Inquiry Learning (POGIL). POGIL presents models that display information through figures, diagrams, and data to students with associated questions for students to answer. The students work together in groups and each member of the group has a specific role such as reader, manager, presenter/recorder, and technician. I was first introduced to POGIL at a North Carolina Science Teachers' Association (NCSTA) conference several years ago. Then I volunteered to be a classroom tester for the POGIL project as the POGIL project developed their models for their high school biology activity book. My experience as a classroom tester with some of the biology models was positive and I observed that my students were engaged and really had to think through the questions that the models presented. From this initial experience, I observed guided inquiry that appeared to be effective in increasing student understanding of various biological concepts presented. Since my exposure to POGIL, I have integrated their activities into my honors biology, chemistry, and environmental science classes. However, despite the anecdotal effectiveness of POGIL in my teaching, I have yet to systematically evaluate the pedagogy.

Having used POGIL activities for the last five years of my teaching, I am interested in learning more about the efficacy of POGIL in teaching and learning biology as compared to a more traditional teacher-centered pedagogy. This led to my focus statement, the purpose of this study is to investigate and evaluate the efficacy of using POGIL in increasing student engagement and achievement in high school biology. In addition, the following sub-questions were researched. 1. What was the effect of using POGIL on student test scores throughout the course? 2. What was the effect of using POGIL on student engagement in high school biology? 3. What was the effect of using POGIL on students' attitudes toward learning high school biology?

CONCEPTUAL FRAMEWORK

POGIL (2016) is a teaching strategy that utilizes collaborative groups that learn through exploring, inventing, and applying concepts. The concepts are presented through models that present information in figures, tables and or diagrams. Each model begins with directed questions that ask students specific questions from the model. Then the questions become more convergent and divergent requiring higher level thinking skills. Students construct their understanding of the content through this approach. There are specific roles for each group member that includes the following: the manager, reader, recorder, and presenter. These roles give participants structure and responsibilities within their collaborative groups. POGIL helps students improve their understanding of concepts, critical thinking skills, application of information, and communication in science (Bailey, Minderhout, & Loertscher, 2011). POGIL has been used as a teaching technique at both the secondary and university levels. POGIL has been implemented in a variety of science courses including: chemistry, physical science, biochemistry, biomechanics, microbiology, anatomy and physiology, nursing, engineering, information technology and introductory STEM classes.

The use of POGIL in the discussion sections of both general and organic chemistry at the post secondary level has been investigated. Specifically, the researchers have examined how adopting POGIL in these courses, effected student achievement, retention, self-efficacy, and attitude toward learning environment as compared to traditional teacher-centered instruction. The results indicated that there was no impact on grades, attitude toward chemistry, and self-efficacy compared to the teacher-centered classes. However, student retention and attitude regarding their learning environment showed positive results in the POGIL group rather than the control group (Chase, Pakhira & Stains, 2013).

In another study, researchers investigated if the use of POGIL was effective in student concept retention and knowledge in organic chemistry at the post-secondary level at Winona State University, Minnesota. Students were taught using the POGIL approach for a full year of organic chemistry class while a comparison group was taught using more traditional methods. The same instructor taught both of these groups. Students' final scores on the American Chemical Society (ACS) exam were compared between the two groups. These studies were repeated for three years. The mean national percentile ranking for traditional vs. POGIL students were 29.0% and 39.2%, respectively and the median national percentile ranking showed 20.0% and 36% respectively. Moreover, 74 students scored above the traditional method mean, representing 72% of the tested group (Hein, 2012).

Although those studies suggest that the use of POGIL is effective, some researchers found differing results, suggesting that the use of POGIL did not improve student performance in chemistry at the university level. Their study with university chemistry students looked at three different groups: partial POGIL, full POGIL, and a control group. Both pre- and post-tests were administered and three exams given to each of the three study groups. The different class means for the first exam were partial POGIL 76.54%, full POGIL 64.28% and control 78.96%. The different class means for the second exam were partial POGIL 68.63%, full POGIL 55.21% and control 71.97%. The third exam class means were partial POGIL 70.83%, full POGIL 59.34% and control 70.73% (Murphy, Picione & Holme, 2010). These results suggest that in this study, the implementation of the POGIL method did not improve student academic performance in college chemistry.

In addition to studies at the university level, researchers investigated the effect of using POGIL to teach organic chemistry to secondary male students in the Caribbean. Specifically, they focused on student academic performance and confidence. Since only a post-test was conducted to measure the academic achievement, and these results were compared to qualitative data from the previous years, the efficacy of utilizing the POGIL strategy was questionable. The results suggest there is a varied academic performance between using traditional teacher-centered and the student-centered POGIL approach indicating that the POGIL students had better results. In terms of student confidence, questionnaires indicated that student academic confidence did increase using the POGIL method as opposed to more traditional teacher-centered methodologies (De Gale & Boisselle, 2015).

Not only has the use of POGIL been conducted in chemistry classes, it has also been used to teach biochemistry. Another study implemented POGIL in a large lecture biochemistry class to create a more student-centered learning environment at the University of Nebraska-Lincoln. The researchers integrated POGIL activities after presenting mini-lectures on content to provide a varied approach during the course period. This therefore should be considered an adaptation of POGIL rather than a full adoption of POGIL. The results of their study indicated that students in the courses using the POGIL strategies showed a statistical significant increase from 9.1 points to 12.5 points out of a total of 21 points on a diagnostic assessment that was taken at the beginning and at the end of the course. Moreover, student surveys showed that 85% of the students agreed that the use of POGIL activities helped them understand the material better and 86% of the students recommended using POGIL activities in the future in the course (Bailey, Minderhout & Loertscher, 2011).

At Seattle University, researchers also investigated the use of adapting POGIL in a biochemistry class. The approach in this study looked at creating a lecture free environment in the teaching of biochemistry. Their results suggest that students gained confidence in understanding course content and critical thinking by solving more complex exam questions. Surveyed students reported that they gained more independence and respect for others through the collaborative learning process that is integral in POGIL implementation (Minderhout & Loertscher, 2006).

The implementation of POGIL has also occurred in a biomechanics course. One study reported that the use of POGIL as compared to a traditional lecture/lab course showed significant gains in student performance. Students reported that they liked the cooperative approach and that this helped them learn the material better. They also felt it improved their understanding of how to apply biomechanical concepts in their daily lives. Students performed better on quizzes, tests and earned overall better grades in the class utilizing the POGIL approach as opposed to the lecture/lab course (Simonson & Shadle, 2013).

Moreover, the use of POGIL in anatomy and physiology classes has also been tested. Researchers tested the efficacy of POGIL at a small private post-secondary school called King College in Bristol, Tennessee. The course adapted POGIL by implementing it in the second half of the second semester of a two-semester course. Fifty percent of lectures in the second semester were replaced using POGIL activities. Student performance improved on summative assessments in that semester. Interestingly, student performance increased in the three semesters after the POGIL approach was implemented. Specifically, the overall course mean scores increased from 76% to 89% and performance on the final exams improved from 68% to 88%. Student surveys indicated that they valued and favored this teaching method (Brown, 2010).

Another study researched various approaches of using POGIL in the teaching of physiological psychology at the university level. The varied approaches tested in the class were as follows: control, POGIL, POGIL without students reporting out, and POGIL implemented with graduate students that were not facilitator trained. Students in all groups were given pre-, post-, and a two-week follow-up tests to evaluate the effectiveness of the various teaching methods. The results in this study indicated that the control and POGIL groups showed no difference in pre- and post- tests as compared to the POGIL with untrained facilitators and POGIL with students not reporting out. However, with the two-week follow up test, the POGIL group recalled more information than all the other groups. This suggests that the use of POGIL can help students retain information over longer periods of time (Vanags, Pammer & Brinker, 2013).

Furthermore, the use of POGIL has been utilized in teaching general STEM courses at the university level. This study evaluated the use of POGIL, “clickers” and a focused science literacy orientation in a STEM course for students not majoring in STEM. Students in this study’s POGIL group reported that they had better understanding in the units taught using this approach as compared to non-POGIL groups Moreover, student performance on summative assessments was higher in the groups taught using the POGIL approach (Jin & Bierma, 2013).

Even though there was some variation in the results from research using the POGIL teaching approach, it is generally thought of as an effective teaching method. Overall, in most of these studies, improvement was found in student class performance. From student surveys, students also appeared to prefer this type of instruction.

METHODOLOGY

The study population of this study included 9th-11th grade biology students at University Christian High School in Hickory, NC. There were two sections of biology with 15 and 8 students respectively. The sample size was 23. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix A). I used the two different sections of my biology class to determine the efficacy of using POGIL in student engagement and achievement in high school biology.

There were a total of four units of study that my research included. Each unit of study was approximately two weeks in length. The treatment group was taught two units using the POGIL strategy using selected activities from the POGIL Activities for High School Biology book (Trout, 2012). The non-treatment group was taught the same two units without the POGIL strategy through traditional lecture and notes. I switched the treatment and non-treatment groups after two units to reduce the effect of class composition on the results and to ensure that every student received the same intervention. The first biology class was taught the two units using the POGIL strategy and the second biology class was taught the same content using traditional teaching methods. The second biology section was taught the other two units using the POGIL strategy while the first section was taught these units using traditional teaching methods.

For each unit, each class took a pretest before the unit began and a post-test after the instruction was completed. The pre/post tests were Cell Structure, Function, and Transport Test (Appendix B), Bioenergetics Test (Appendix C), Reproduction, Growth, and Development Test (Appendix D), and Ecology Test (Appendix E). Basic descriptive statistics were recorded for both the pre- and post-test data. The pre- and post-test data were analyzed for normalized gains in both groups. Normalized gains were then compared between the treatment and comparison groups. According to Hake (1998), *high* normalized gain scores are greater or equal to .7, *medium* scores are between greater or equal to .3 but less than .7, and *low* scores are less than .3. The post-test scores were analyzed using the Randomization/Permutation Test to compare significant differences between groups. The confidence interval was 95%. Moreover, there was one quiz per unit; Cell Structure and Function Quiz (Appendix F), ATP and Photosynthesis Quiz (Appendix G), Cell Size and Cycle Quiz (Appendix H), and Energy Flow and Nutrient Cycles Quiz (Appendix I). Basic descriptive statistics were recorded for each of the four quizzes. Quiz scores were compared using the Randomization/Permutation Test to see if there was a significant difference between the treatment and the non-treatment groups.

Furthermore, after the two units of biology, the treatment and non-treatment groups each took the Post Treatment Questionnaire to determine their engagement and perception of the teaching method received (Appendix J). There were 10 Likert-survey statements on the questionnaire with options of *strongly agree, agree*, *neutral*, *disagree*, and *strongly disagree* for the students to choose from. The results for each questionnaire item were recorded. The students took the survey twice, once after being in the treatment group and once after being in the non-treatment group. The survey data was analyzed using the Fisher's Exact Test to see if there was a significant difference between the treatment and the non-treatment group responses based on their experience in the treatment and non-treatment groups. The confidence interval was 95%. Observations were also made and recorded to measure student engagement and attitudes towards learning biology using POGIL.

At the conclusion of the study, eight students were selected to be interviewed regarding their experience using the POGIL teaching strategy using the Post Treatment Interview Questions (Appendix K). Student responses were recorded and analyzed for trends in their responses. The main focus statement and sub-questions, along with the data collection instruments used to answer those questions are summarized in Table 1.

Table 1
Data Triangulation Matrix

Research Questions	Data Source 1	Data Source 2	Data Source 3
Did student test scores improve in biology?	Unit Pre-Tests	Unit Post-Tests	Quizzes
Did student engagement increase in biology?	Post Treatment Questionnaire	Student Interviews	Observations/Journal
Was there a positive attitude towards learning biology?	Post Treatment Questionnaire	Student Interviews	Observations/Journal

DATA AND ANALYSIS

The results from the non-treatment group on the Cell Structure, Function and Transport Pre-test, a test that measured comprehension, analysis, and application of cell biology concepts, indicated a mean of 39% whereas the treatment group had a mean of 29% (*N*=23). These results were before any teaching intervention or treatment actually was implemented. The results of the Cell Structure, Function and Transport Post-test for the non-treatment group indicated a post-test mean of 75% with an average of normalized gains to be .55 between pre- and post-tests, a *medium* gain. The treatment group had a post test average of 85% with a *high* average of normalized gains to be .79 (Figure 1).

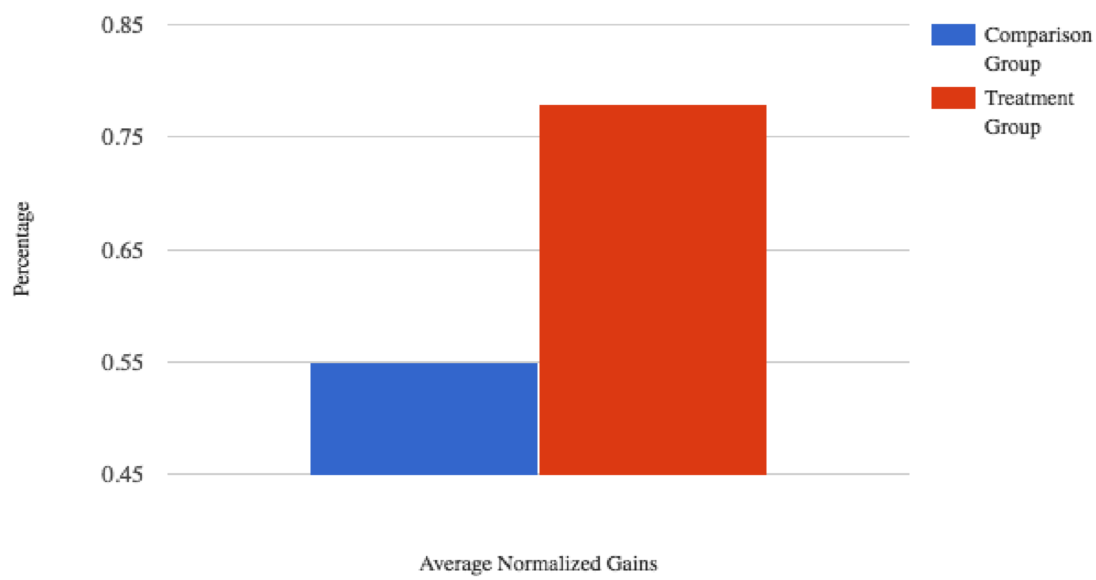

Figure 1. Average normalized gains for the Cell Structure, Function and Transport Pre and Post Tests for the non-treatment (comparison) and treatment groups.

To determine if the difference in the normalized gains between groups were significant, a Randomization/Permutation Test was performed since my sample sizes were so small. The results of the Randomization/Permutation Test indicated a p-value of 0.0001671, which was less than the alpha value of .05. Since the p-value was less than the alpha value, the null hypothesis was rejected. The null hypothesis was that there was no treatment effect, which means that POGIL did not have an effect on scores whereas the alternative hypothesis was that there was a treatment effect and that POGIL did have an effect on scores.

Moreover, a Randomization/Permutation Test was performed just on the post-test scores to determine if the difference was statistically significant. The results of the Randomization/Permutation Test for the post-test data indicated a p-value of 0.02962, was less than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was less than the alpha value, the null hypothesis was rejected.

The results from the non-treatment group on the Bioenergetics Pre-test, a test that measured comprehension, analysis, and application of energy transformation and transfer concepts, indicated a mean of 37% whereas the treatment group had a mean of 32% (N=23). These results were before any teaching intervention or treatment actually was implemented. The results of the Bioenergetics Post-test for the non-treatment group indicated a post-test mean of 73% with an average of normalized gains to be .59 between pre- and post-tests, a *medium* gain. The treatment group had a post test average of 84% with a high average of normalized gains to be .77 (Figure 2).

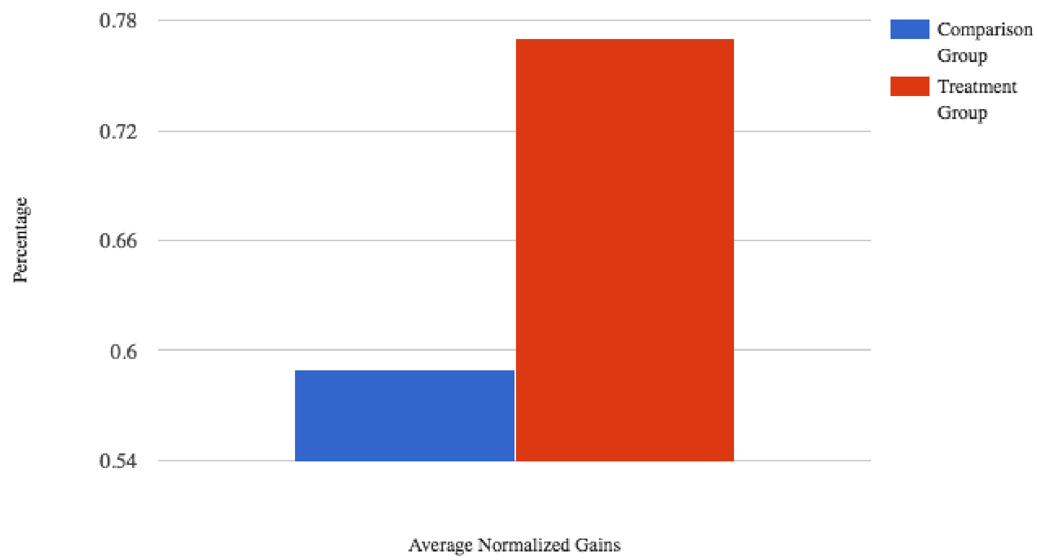

Figure 2. Average normalized gains for the Bioenergetics Pre and Post Tests for the non-treatment (comparison) and treatment groups.

To determine if the difference in the normalized gains between groups were significant, a Randomization/Permutation Test was performed since my sample sizes were so small. The results of the Randomization/Permutation Test indicated a p-value of 0.006843, was less than the alpha value of .05. Since the p-value was less than the alpha value, the null hypothesis was rejected. The null hypothesis was that there was no treatment effect whereas the alternative hypothesis was that there was a treatment effect.

Moreover, a Randomization/Permutation Test was performed just on the post-test scores to determine if the difference was statistically significant. The results of the Randomization/Permutation Test for the post-test data indicated a p-value of 0.02233, was less than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was less than the alpha value, the null hypothesis was rejected.

The results from the non-treatment group on the Reproduction, Growth and Development Pre-test, a test that measured comprehension, analysis, and application of cell division and organism development concepts, indicated a mean of 33% whereas the treatment group had a mean of 29% (*N*=23). These results were before any teaching intervention or treatment actually was implemented. The results of the Reproduction, Growth and Development Post-test for the comparison group indicated a post-test mean of 74% with an average of normalized gains to be .63 between pre- and post-tests, a *medium* gain. The treatment group had a post test average of 79% with a *high* average of normalized gains to be .70 (Figure 3).

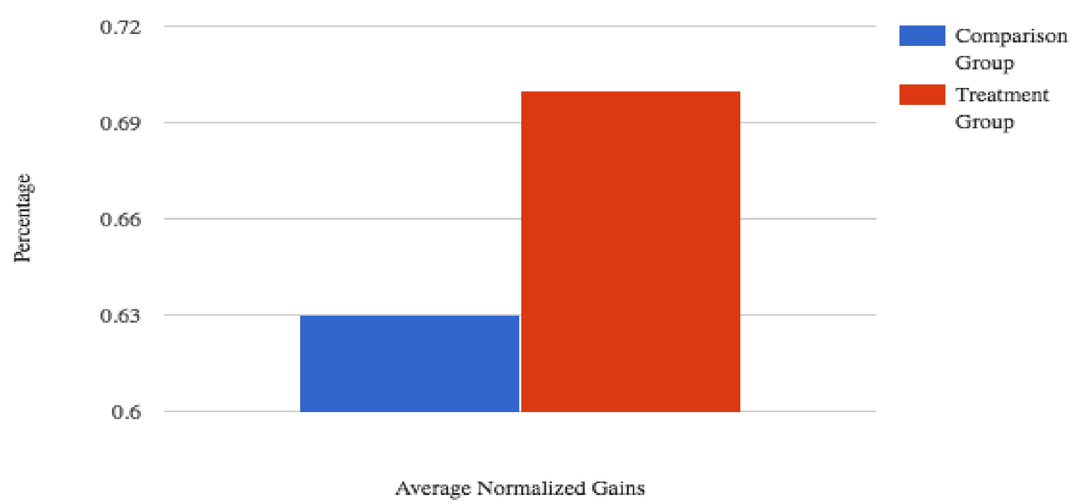

Figure 3. Average normalized gains for the Reproduction, Growth and Development Pre and Post Tests for the non-treatment (comparison) and treatment groups.

To determine if the difference in the normalized gains between groups were significant, a Randomization/Permutation Test was performed since my sample sizes were so small. The results of the Randomization/Permutation Test indicated a p-value of 0.4022, was greater than the alpha value of .05. Since the p-value was greater than the alpha value, I failed to reject the null hypothesis. The null hypothesis was that there was no treatment effect whereas the alternative hypothesis was that there was a treatment effect.

Moreover, a Randomization/Permutation Test was performed just on the post-test scores to determine if the difference was statistically significant. The results of the Randomization/Permutation Test for the post-test data indicated a p-value of 0.3822, was greater than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was greater than the alpha value, I failed to reject the null hypothesis.

The results from the non-treatment group on the Ecology Pre-test, a test that measured comprehension, analysis, and application of ecology concepts, indicated a mean of 51% whereas the treatment group had a mean of 53% (N=23). These results were before any teaching intervention or treatment actually was implemented. The results of the Ecology Post-test for the non-treatment group indicated a post-test mean of 74% with an average of normalized gains to be .49 between pre- and post-tests, a *medium* gain. The treatment group had a post test average of 87% with a *high* average of normalized gains to be .76 (Figure 4).

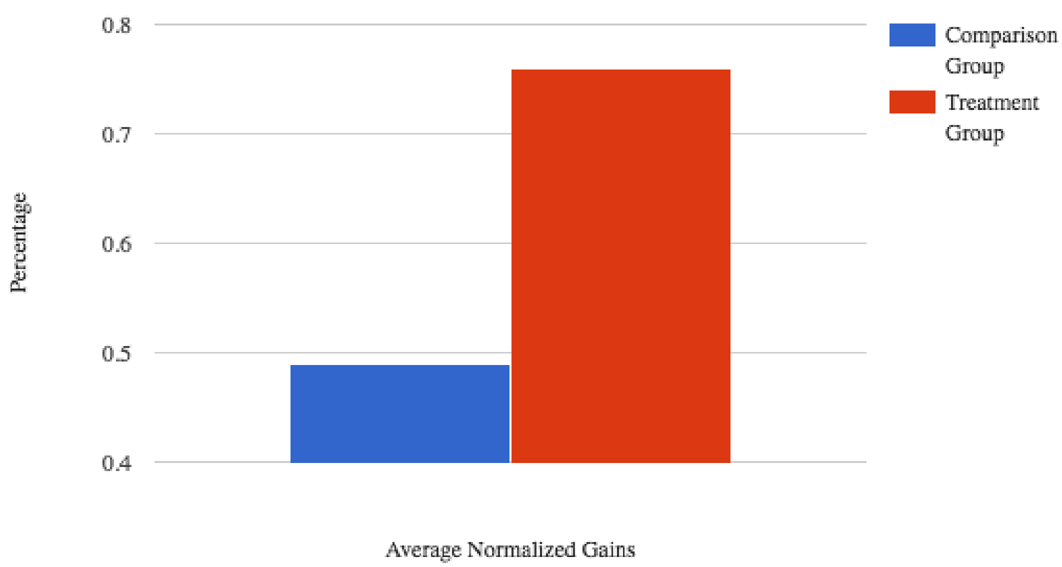

Figure 4. Average normalized gains for the Ecology Pre and Post Tests for the non-treatment (comparison) and treatment groups.

To determine if the difference in the normalized gains between groups were significant, a Randomization/Permutation Test was performed since my sample sizes were so small. The results of the Randomization/Permutation Test indicated a p-value of 0.00146 was less than the alpha value of .05. Since the p-value was less than the alpha value, the null hypothesis was rejected. The null hypothesis was that there was no treatment effect whereas the alternative hypothesis was that there was a treatment effect.

Moreover, a Randomization/Permutation Test was performed just on the post-test scores to determine if the difference was statistically significant. The results of the Randomization/Permutation Test for the post-test data indicated a p-value of 0.02219 was less than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was less than the alpha value, the null hypothesis was rejected. The results of the average normalized gains for the unit pre and post-tests are summarized in Table 2.

Table 2
Unit Pre and Post Test Data Summary

Unit Test	Non-Treatment Group Normalized Gains Mean	Treatment Group Normalized Gains Mean	P-Value	Significant
Cell Structure, Function & Transport	.55	.79	0.0001671	Yes
Bioenergetics	.59	.77	0.006843	Yes
Reproduction, Growth & Development	.63	.70	0.4022	No
Ecology	.49	.76	0.00146	Yes

The results for the Cell Structure and Function quiz indicated a mean for the non-treatment group of 79%, whereas the mean for the treatment group was 89% (*N*=23). Due to small sample size and to determine if the difference in these quiz scores was statistically significant, a Randomization/Permutation Test was performed. The results of the Randomization/Permutation Test for the Cell Structure and Function quiz data indicated a p-value of 0.02754 was less than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was less than the alpha value, the null hypothesis was rejected.

The results of the ATP and Photosynthesis quiz indicated a mean for the non-treatment group of 77%, whereas the mean for the treatment group was 86% (*N*=23). Due to small sample size and to determine if the difference in these quiz scores was statistically significant, a Randomization/Permutation Test was performed. The results of the Randomization/Permutation Test for the ATP and Photosynthesis quiz data indicated a p-value of 0.1189 was greater than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Since the p-value was greater than the alpha value, I failed to reject null hypothesis.

The results for the Cell Size and Cycle quiz indicated a mean for the non-treatment group of 73%, whereas the mean for the treatment group was 85% (*N*=23). Due to small sample size and to determine if the difference in these quiz scores was statistically significant, a Randomization/Permutation Test was performed. The results of the Randomization/Permutation Test for the Cell Size and Cycle quiz data indicated a p-value of 0.03496 was less than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was less than the alpha value, the null hypothesis was rejected.

The results for the Energy Flow and Nutrient Cycles quiz indicated a mean for the non-treatment group of 75%, whereas the mean for the treatment group was 87% (*N*=23). Due to small sample size and to determine if the difference in these quiz scores was statistically significant, a Randomization/Permutation Test was performed. The results of the Randomization/Permutation Test for the Energy Flow and Nutrient quiz data indicated a p-value of 0.009518 was less than the alpha value of .05. The null hypothesis was that there was no treatment effect and the alternative hypothesis was that there was a treatment effect. Again, since the p-value was less than the alpha value, the null hypothesis was rejected. The results of the quizzes are summarized in Table 3.

Table 3
Quiz Data Summary

Quiz	Non-Treatment Group Mean	Treatment Group Mean	P-Value	Significant
Cell Structure & Function	79%	89%	0.02754	Yes
ATP & Photosynthesis	77%	86%	0.1189	No
Cell Size & Cycle	73%	85%	0.03496	Yes
Energy Flow & Nutrient Cycles	75%	87%	0.009518	Yes

The results of the first round of the Post-Treatment Questionnaire indicated that 87% of the students in the treatment group reported that they *strongly agreed* or *agreed* that the class activities helped them improve their oral presentation communication skills by exchanging information through speaking and listening whereas only 25% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement (*N*=23). In the treatment group, 93% of the students either *strongly agreed* or *agreed* that the class activities helped them improve their written communication skills by passing information and understanding to the class through written materials whereas in the non-treatment group none of the students *strongly agreed* or *agreed* with that statement. In the treatment group, 80% of the students *strongly agreed* or *agreed* that the interaction with others during the class activities helped them improve their teamwork by working towards a common goal while none of the students in the non-treatment group *strongly agreed* or *agreed* with that statement.

Moreover, 87% of the students in the treatment group either *strongly agreed* or *agreed* with the statement that the class activities helped them improve their critical thinking skills by analyzing information to form an argument or reach a conclusion supported by evidence while only 13% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement. In the treatment group, 87% of the students either *strongly agreed* or *agreed* with the statement that the class activities helped improve their planning, organizing, and coordinating efforts to accomplish a goal whereas only 25% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement. In the treatment group 93% of the students either *strongly agreed* or *agreed* that the class activities helped them process information through evaluating and interpreting information presented in models, diagrams and text while only 25% of the students in the non-treatment group answered in a similar fashion. The results of the question related to the development of skills from the POGIL strategy being useful in other classes, again 75% of the students responded that they thought the skills they were developing in biology using POGIL would be helpful in other classes and outside of class. One student responded, “I think each of us taking turns being a leader/manager, reader, recorder, and presenter helped us get better at those roles and those things are important in other classes too.” Another student added, “I think it could help in some of our after school groups like sports and clubs where we each have a part in the group to help the group or team be better."

Furthermore, in the treatment group 80% of the students either *strongly agreed* or *agreed* with the statement that the class activities helped them reflect on their own learning and participation in the group in order to be successful but only 13% of the students in the non-treatment group felt the same. In the treatment group, 87% of the students either *strongly agreed* or *agreed* with the statement that the class activities helped them become more confident in learning and understanding biology whereas only 38% of students in the non-treatment group responded the same way. The results of the Post Treatment Interview Questions indicated that 75% of the students answered in the affirmative that the use of POGIL helped them think differently about the biology content when compared to traditional teacher lecturing and note taking (N=8). One student said, "I really thought about the material more. The diagrams and questions that went with them really made me think about what I was looking at and how to make sense of information shown in the diagrams." Another student added, "I liked the POGIL stuff more because we could talk about the material in our groups to help each other understand it more than just listening to you talk about the information from Power Point slides."

In addition, 67% of the students in the treatment group either *strongly agreed* or *agreed* that that the class activities helped them think about their own thinking, how they learn and being more aware of their own knowledge while 25% of the students in the non-treatment group felt the same. In the treatment group, 93% of the students either *strongly agreed* or *agreed* with the statement that the class activities prepared them to do better on biology assessments (quizzes and tests), but only 25% of the students in the non-treatment group responded in the same way.

After two units of biology were taught, the treatment and non-treatment groups switched so the students took the Post-Treatment Questionnaire again. The results of the second round of the Post-Treatment Questionnaire indicated that 50% of the students in the treatment group reported that they *strongly agreed* or *agreed* that the class activities helped them improve their oral presentation communication skills by exchanging information through speaking and listening whereas 27% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement (*N*=23). In the treatment group, 88% of the students either *strongly agreed* or *agreed* that the class activities helped them improve their written communication skills by passing information and understanding to the class through written materials whereas in the non-treatment group 20% of the students *strongly agreed* or *agreed* with that statement. In the treatment group, 88% of the students *strongly agreed* or *agreed* that the interaction with others during the class activities helped them improve their teamwork by working towards a common goal while 33% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement.

Moreover, 100% of the students in the treatment group either *strongly agreed* or *agreed* with the statement that the class activities helped them improve their critical thinking skills by analyzing information to form an argument or reach a conclusion supported by evidence while only 27% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement. In the treatment group, 93% of the students either *strongly agreed* or *agreed* with the statement that the class activities helped improve their planning, organizing, and coordinating efforts to accomplish a goal whereas only 20% of the students in the non-treatment group *strongly agreed* or *agreed* with that statement. In the treatment group 100% of the students either *strongly agreed* or *agreed* that the class activities helped them process information through evaluating and interpreting information presented in models, diagrams and text while 33% of the students in the non-treatment group answered in a similar fashion. In addition, 100% of the students interviewed indicated that they felt more engaged in class when we used POGIL compared to the traditional teacher centered lecture and note taking strategy. One student said, "I get bored in lecture but liked the POGIL a lot more because we had time to talk about the material more, take turns being a leader or presenter, and helping each other figure out what was being presented in the models and what it meant." Another student mentioned, "I tend to zone out in class when it's a lecture and really liked the group aspect of the POGIL activities more. It helped me pay attention more in class." The results from the question asking about attitude towards biology based on teaching strategy indicated that 63% of the students responded that they had a more positive attitude towards learning about biology when using POGIL compared to when not using it. One student stated, "When I knew we were going to be in our POGIL groups, class is more interesting and fun. I get biology better when we use POGIL." Another student mentioned, "Unless we were doing a lab, I kind of thought science was boring but POGIL kept me more interested in biology compared to lecture."

Additionally, in the treatment group 100% of the students either *strongly agreed* or *agreed* with the statement that the class activities helped them reflect on their own learning and participation in the group in order to be successful while 27% of the students in the non-treatment group felt the same. In the treatment group, 88% of the students either *strongly agreed* or *agreed* with the statement that the class activities helped them become more confident in learning and understanding biology whereas only 33% of students in the non-treatment group responded the same way. In the treatment group, 63% of the students either *strongly agreed* or *agreed* that that the class activities helped them think about their own thinking, how they learn and being more aware of their own knowledge while 27% of the students in the non-treatment group felt the same. In the treatment group, 100% of the students either *strongly agreed* or *agreed* with the statement that the class activities prepared them to do better on biology assessments (quizzes and tests), but only 20% of the students in the non-treatment group responded in the same way. Furthermore, 50% of the students responded that if they were going to change anything about using POGIL, that somehow use it when we would do labs while the other 50% of the students did not identify anything to change. One student mentioned, "When we did labs, we really didn't have the roles we would have in the POGIL activities and that was ok but sometimes our groups felt disorganized and what would be doing became more confusing." Another student added, "I liked the POGIL groups and I think it would be good to have lab activities that are similar to the POGIL activities we did in class. I felt like biology made more sense using them." The question asking students to summarize their experience using POGIL indicated that 88% of the students had a positive experience using POGIL and the 12% who didn't simply preferred the traditional teacher centered teaching strategy. One student mentioned, "POGIL made class more fun and I felt that I remembered more of the information better." Another student claimed, "I liked working with different people in the groups and trying new roles in the group." Another student said, "I liked being able to discuss the information in class in our groups. This really helped me understand biology a lot better."

From observations in class, students who were in the treatment group, were more engaged and actively participating in class by asking questions, reading information, debating responses, challenging each other's interpretations, and presenting their responses whereas students in the comparison group were more passive and there was much less student interaction with the exception of lab days.

The results of the Fisher 's Exact Test for the first round of the post treatment questionnaire responses are shown in Table 4 and the results of Fisher's Exact Test for the second round of the Post-Treatment Questionnaire responses are shown in Table 5. Only responses that showed statistical significance were included in Tables 4 and 5. Questions from the post-treatment questionnaire that didn't show statistical significance were omitted from Tables 4 and 5.

Table 4

Results of the Fisher's Exact Test for the First Round of the Post-Treatment Questionnaire Reponses

Hypotheses H_O: Null Hypothesis H_A: Alternative Hypothesis	P-Value, Significant & Reject H_0
1. H_O: Class activities and improvement in oral communication skills by exchanging information through speaking and listening are independent. H_A: Class activities and improvement in oral communication skills by exchanging information through speaking and listening are not independent.	0.01276 Yes Reject
2. H_O: Class activities and improvement in written communication skills by passing information and understanding to the class through written materials are independent. H_A: Class activities and improvement in written communication skills by passing information and understanding to the class through written materials are not independent.	5.507e-05 Yes Reject
3. H_O: The interaction with others during class activities and improved teamwork by working towards a common goal are independent. H_A: The interaction with others during class activities and improved teamwork by working towards a common goal are not independent.	0.001454 Yes Reject
4. H_O: Class activities and improved critical thinking skills by analyzing information to form an argument or reach a conclusion by evidence are independent. H_A: Class activities and improved critical thinking skills by analyzing information to form an argument or reach a conclusion by evidence are not independent.	0.004938 Yes Reject
6. H_O: Class activities and better processing of information through evaluating and interpreting information presented in models, diagrams, and text are independent. H_A: Class activities and better processing of information through evaluating and interpreting information presented in models, diagrams, and text are not independent.	0.003308 Yes Reject
8. H_O: Class activities and improved confidence in learning and understanding biology are independent. H_A: Class activities and improved confidence in learning and understanding biology are not independent.	0.0246 Yes Reject
10. H_O: Class activities and better preparation for biology assessments are independent. H_A: Class activities and better preparation for biology assessments are not independent.	0.01531 Yes Reject

Table 5
Results of the Fisher's Exact Test for the Second Round of the Post-Treatment Questionnaire Reponses

Hypotheses H_O: Null Hypothesis H_A: Alternative Hypothesis	P-Value, Significant, & Reject H_0
2. H_O: Class activities and improvement in written communication skills by passing information and understanding to the class through written materials are independent. H_A: Class activities and improvement in written communication skills by passing information and understanding to the class through written materials are not independent.	0.01726 Yes Reject
3. H_O: The interaction with others during class activities and improved teamwork by working towards a common goal are independent. H_A: The interaction with others during class activities and improved teamwork by working towards a common goal are not independent.	0.02837 Yes Reject
4. H_O: Class activities and improved critical thinking skills by analyzing information to form an argument or reach a conclusion by evidence are independent. H_A: Class activities and improved critical thinking skills by analyzing information to form an argument or reach a conclusion by evidence are not independent.	0.002084 Yes Reject
6. H_O: Class activities and better processing of information through evaluating and interpreting information presented in models, diagrams, and text are independent. H_A: Class activities and better processing of information through evaluating and interpreting information presented in models, diagrams, and text are not independent.	0.00633 Yes Reject
8. H_O: Class activities and improved confidence in learning and understanding biology are independent. H_A: Class activities and improved confidence in learning and understanding biology are not independent.	0.01284 Yes Reject
10. H_O: Class activities and better preparation for biology assessments are independent. H_A: Class activities and better preparation for biology assessments are not independent.	0.002221 Yes Reject

INTERPRETATION AND CONCLUSION

The first research question I wanted to address was whether or not student test scores improve in biology. From the normalized gains between the pre and post-tests, both the comparison group and treatment group showed growth. However, the treatment group had higher normalized gains in all pre/post-tests compared to the treatment group. The normalized gains for the treatment group were statistically significantly different than the non-treatment group in three out of four of the pre/post-tests. Since the null hypothesis that there was no treatment effect was rejected for Cell Structure, Function, and Transport test, Bioenergetics test, and the Ecology test, this suggests that there was a treatment effect for these assessments. This supports the teaching strategy that POGIL did increase test scores in biology for these three units.

In addition to the pre/post-test scores, the quiz scores also supported the claim that POGIL increases assessment scores. Again, for all the quiz scores, the treatment mean score was higher than the non-treatment group mean score. In three out of four quizzes, the difference between quiz scores was significant so the null hypothesis that there was no treatment effect was rejected. For the Cell Structure and Function quiz, Cell Size and Cycle quiz, and Ecology quiz, the alternative hypothesis was accepted that there was a treatment effect.

The second research question I wanted to address was whether or not student engagement increased in biology. From the Post-Treat Questionnaire, more students in the treatment group either strongly agreed or agreed more often with the statements that the class activities improved their teamwork, written communication skills, critical thinking skills, and processing information when compared to learning in a teacher centered lecture/note taking class structure. The difference in the non-treatment and treatment groups in both rounds of the Post-Treatment Questionnaire was statistically significant. This suggests that the class activities and improved teamwork, written communication skills, critical thinking skills, and processing information were not independent and that there was a treatment effect.

Also, in the Post-Treatment Interview Questions, 100% of the students interviewed indicated that they felt more engaged in class when we used POGIL compared to the traditional teacher centered lecture and note taking strategy. I also made observations when conducting the research to see how student engagement differed between the comparison and treatment groups. I consistently observed that during teacher centered lecture based instruction that the students were generally passive and asked questions occasionally but in most cases just sat passively and recorded notes and answered questions if I posed them. On the other hand, in the treatment group, students were discussing the models and questions with each other to make sense of the material presented. I rotated around and listened to the conversation at each table and for the most part, the students were on task discussing the information presented in the POGIL activities. The results of the Post-Treatment Questionnaire, Interview Questions and my observations support the claim that POGIL increased student engagement in biology.

The third research question I wanted to address was whether or not there was a positive attitude towards learning biology. From the Post-Treatment Questionnaire, students in the treatment group responded either strongly agreed or agreed that the class activities help them improve their confidence in learning and understanding biology as well as helped prepare them for biology assessments like tests and quizzes. The difference in the responses between the treatment and comparison groups were statistically significant so the null hypothesis that class activities and improved confidence in biology and better preparation for biology assessments were independent was rejected and that the alternative hypothesis that they were not independent was accepted which suggests that there was a treatment effect.

Furthermore, student responses from the Post-Treatment Interview indicated that most of the students preferred to learn through POGIL and felt had a more positive attitude towards biology as a result. From my own observations in class, the energy level in the classroom was much higher and students were much more enthusiastic when we were learning biology through the POGIL strategy as compared to the traditional teacher centered lecture/note taking based method. The results of the Post-Treatment Questionnaire, Interview Questions and my observations support the claim that POGIL showed a positive attitude towards learning biology.

VALUE

I have been using POGIL activities for a while after first being introduced to the strategy at a workshop. However, I was not properly trained to facilitate the strategy as designed. Yet, I found the students to be challenged and forced to think about the material more than if I were to just lecture about it. In the summer of 2016, I decided to attend two formal POGIL training workshops each approximately one week long prior to implementing my action research. I found the research rewarding and the results very reaffirming. I think this strategy does a great job engaging students, improving content knowledge and developing skills that are transferable to other classes and potential work environments. The students interacted much more using the POGIL and seemed to articulate the concepts learned better using POGIL than not using POGIL. I enjoyed watching the student interaction and how the students challenged each other on questions in a respectful way. The students seemed to understand the content at a deeper level than through passive reception from lecture using Power point slides or written notes on the whiteboard.

The action research-based classroom project really changed how I taught biology this year. After going through the training, I felt more comfortable and confident in facilitating the POGIL process in my class. I carefully described the specific roles each student would have at some time using this strategy and tried to model that for them. The students generally assumed their roles as expected and rotated through them during each POGIL activity. Students who were normally more reticent started to speak up more when we used the POGIL activities. One challenge was dealing with the diverse personalities in the class. I tried to rotate groups consistently so certain personalities didn't dominate the activity and sabotage the collaborative process. I plan on using this strategy moving forward and want to develop some of my own POGIL activities for biology that aren't in the POGIL activity book as well as develop some activities for other areas of science where they may not yet exist such as in environmental science. One goal I have is to transform my labs I used in biology to be more in line with the POGIL teaching and learning method. One of the workshops I went to last summer began to address how that can be done.

Additionally, I think the students for the most part benefitted from learning biology as well as other skills through this method and I plan to utilize it more often moving forward. I am happy with the results and experience from this action research project and I think I will be a better teacher and my students will also do better in biology as a result. I am proud of my students for buying into this strategy after being accustomed to learning in a more passive way in the past and giving this a chance. I think they feel the same in retrospect as indicated in the interview. This entire process showed me the value of action research and to look at myself as a teacher to really see if the methods I'm using are actually effective. I feel validated from this experience.

This research has also brought up additional questions:

Can this teaching method be used in other areas of learning like the social sciences, language arts, and mathematics?

Are their additional roles not yet identified that could be added to the POGIL process to develop additional skills?

What ages are most appropriate to use POGIL activities? Can current activities be modified to reach younger and older learners or exceptional learners?

These are just a few of the questions that this research has made me think about and that could be useful in researching to improving teaching learning for all. This action research-based classroom project suggests how important inquiry can be in increasing student engagement, developing critical thinking skills, analyzing data, drawing conclusions based on evidence, and improving performance in science based assessments.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

MONTANA STATE UNIVERSITY

960 Technology Blvd. Room 127
c/o Immunology & Infectious Diseases
Montana State University
Bozeman, MT 59718
Telephone: 406-994-6783
FAX: 406-994-4303
E-mail: cherylj@montana.edu

Chair: Mark Quinn
406-994-5721
mquinn@montana.edu
Administrator:
Cheryl Johnson
406-994-6783
cherylj@montana.edu

MEMORANDUM

TO: Derek Chase and John Graves

FROM: Mark Quinn, Chair *Mark Quinn cj*

DATE: August 2, 2016, 2016

RE: *"The Efficacy of POGIL in Teaching & Learning in High School Biology" [DC080216-EX]*

The above research, described in your submission of August 2, 2016, 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:

____ (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.

____ (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

CELL STRUCTURE, FUNCTION AND TRANSPORT TEST

Cell Structure, Function and Transport Test

Multiple Choice

Identify the choice that best completes the statement or answers the question.

____ 1. Looking at a cell under a microscope, you note that it is a prokaryote. How do you know?

a. The cell lacks cytoplasm.
b. The cell lacks a cell membrane.
c. The cell lacks a nucleus.
d. The cell lacks genetic

____ 2. Which of the following enclose their DNA in a nucleus?

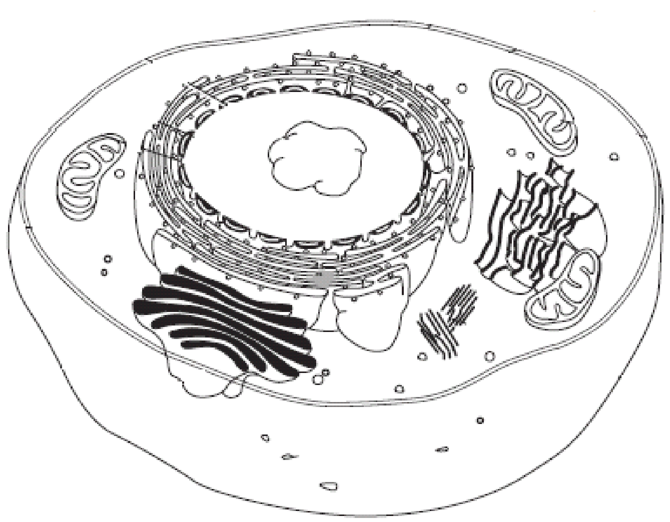
a. prokaryotes
b. bacteria
c. eukaryotes
d. viruses

____ 3. Prokaryotes usually have

a. a nucleus.
b. specialized organelles.
c. genetic material.
d. many cells.

____ 4. Which of the following organisms are prokaryotes?

a. plants b. animals c. bacteria d. fungi



____ 5. Which of the following conclusions could you draw about the cell shown in the figure above?

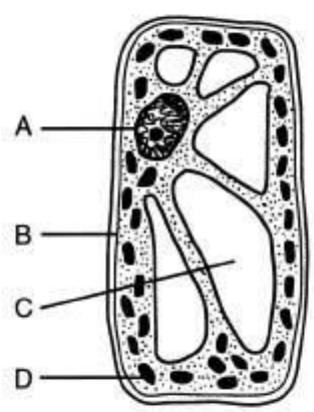
a. The cell is eukaryotic because it has a nucleus.
b. The cell is prokaryotic because it has a nucleus.
c. The cell is eukaryotic because it does not have a
d. The cell is prokaryotic because it does not have a

____ 6. Which of the following is a function of the nucleus?
- a. stores DNA
- b. stores sugars
- c. builds proteins
- d. packages proteins

____ 7. Which of the following is NOT found in the nucleus?
- a. mitochondria
- b. nucleolus
- c. chromatin
- d. DNA

____ 8. Which of the following statements about the nucleus is NOT true?
- a. The nucleus stores the coded instructions for making the cell's proteins.
- b. The nucleus usually contains a nucleolus region, which is where ribosome assembly begins.
- c. The nucleus is the site of protein assembly.
- d. The nucleus is surrounded by a nuclear envelope that lets materials in and out.

____ 9. Which organelle breaks down organelles that are no longer useful?
- a. Golgi apparatus
- b. lysosome
- c. endoplasmic reticulum
- d. mitochondrion



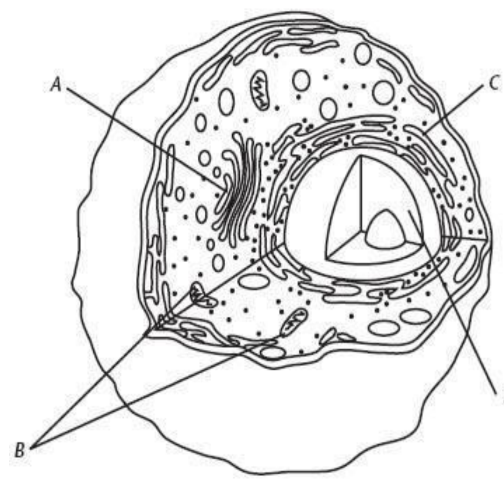
____ 10. Which structure in the cell shown in the figure above stores materials, such as water, salts, proteins, and carbohydrates?
- a. structure A
- b. structure B
- c. structure C
- d. structure D

____ 11. Cells that actively produce proteins will contain large numbers of which organelles?

a. Golgi apparatus
b. mitochondria
c. vacuoles
d. ribosomes

____ 12. Which sequence correctly traces the path of a protein in the cell?
a. ribosome, endoplasmic reticulum, Golgi
b. ribosome, endoplasmic reticulum, chloroplast
c. endoplasmic reticulum, lysosome, Golgi
d. ribosome, Golgi apparatus, endoplasmic

Cell Structures



____ 13. Which structure in the cell shown in the figure above modifies, sorts, and packages proteins and other materials for storage or release from the cell?
a. structure A
b. structure B
c. structure C
d. structure D

____ 14. Which organelle converts the chemical energy stored in food into compounds that are more convenient for the cell to use?
a. chloroplast
b. Golgi apparatus
c. endoplasmic reticulum
d. mitochondrion

____ 15. Which organelles are involved in energy conversion?
a. mitochondria and chloroplasts
b. mitochondria and ribosomes
c. smooth and rough endoplasmic
d. Golgi apparatus and chloroplasts

____ 16. Which organelle would you expect to find in plant cells but not animal cells?

a. mitochondrion
b. ribosome
c. chloroplast
d. smooth endoplasmic

_____ 17. The primary function of the cell wall is to
a. support and protect the cell.
b. store DNA.
c. direct the activities of the
d. help the cell move.

_____ 18. Unlike the cell membrane, the cell wall is
a. found in all organisms.
b. composed of a lipid bilayer.
c. selectively permeable.
d. a rigid structure.

_____ 19. You will NOT find a cell wall in which of these kinds of organisms?
a. plants b. animals c. fungi d. bacteria

_____ 20. Which of the following structures serves as the cell's boundary from its environment?
a. mitochondrion
b. cell membrane
c. chloroplast
d. channel protein

_____ 21. Which of the following is a function of the cell membrane?
a. breaks down lipids, carbohydrates, and proteins from
b. stores water, salt, proteins, and carbohydrates
c. keeps the cell wall in place
d. regulates the movement of materials into and out of the

_____ 22. The cell membrane contains channels and pumps that help move materials from one side to the other. What are these channels and pumps made of?
a. carbohydrates
b. lipids
c. bilipids
d. proteins

_____ 23. Diffusion occurs because
a. molecules are attracted to one another.
b. molecules constantly move and collide with each other.
c. cellular energy forces molecules to collide with each
d. cellular energy pumps molecules across the cell

_____ 24. During diffusion, when the concentration of molecules on both sides of a membrane is the same, the molecules will
a. move across the membrane to the outside of the cell.
b. stop moving across the membrane.
c. continue to move across the membrane in both
d. move across the membrane to the inside of the cell.

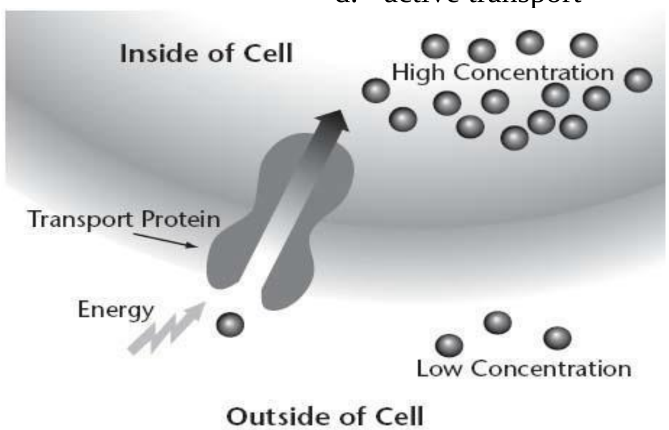
_____ 25. The diffusion of water across a selectively permeable membrane is called
a. phagocytosis.
b. osmosis.
c. pinocytosis.
d. active transport.

_____ 26. An animal cell that is surrounded by fresh water will burst because the osmotic pressure causes

a. water to move into the cell.
b. water to move out of the cell.
c. solutes to move into the cell.
d. solutes to move out of the cell.

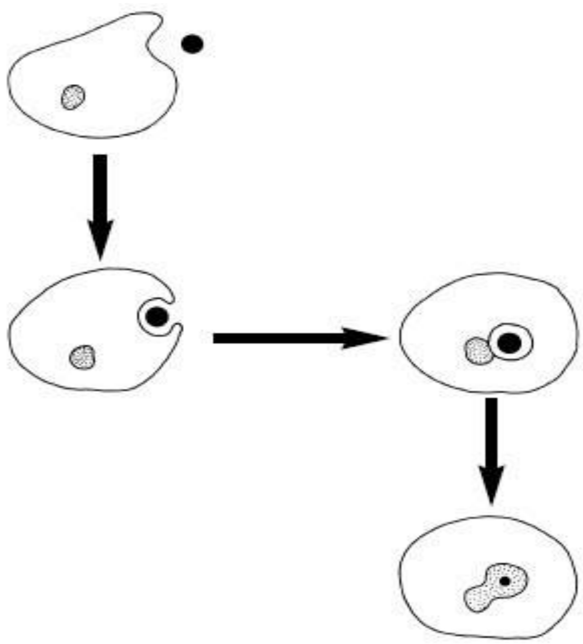
_____ 27. Which means of particle transport requires input of energy from the cell?

a. diffusion
b. osmosis
c. facilitated diffusion
d. active transport



_____ 28. Which means of particle transport is shown in the figure above?

a. diffusion
b. osmosis
c. facilitated diffusion
d. active transport



____ 29. Which means of particle transport is shown in the figure above?
a. endocytosis
b. exocytosis
c. facilitated diffusion
d. protein pump

____ 30. Which of the following activities is NOT a way that unicellular organisms maintain homeostasis?
a. reproduction
b. growth
c. cell specialization
d. response to the

____ 31. Which term describes the relatively constant internal physical conditions of an organism?
a. cell specialization
b. homeostasis
c. organ system
d. unicellularity

____ 32. The cells of unicellular organisms are
a. specialized to perform different tasks.
b. larger than those of multicellular organisms.
c. able to carry out all of the functions necessary for
d. unable to respond to changes in their environment.

____ 33. A group of similar cells that perform a particular function is called
a. an organ.
b. an organ system.
c. a tissue.
d. a division of labor.

____ 34. An organ system is a group of organs that
a. are made up of similar cells.
b. are made up of similar tissues.
c. work together to perform a specific function.
d. work together to perform all the functions in a multicellular

____ 35. Which list represents the levels of organization in a multicellular organism from the simplest level to the most complex level?
a. cell, tissue, organ system, organ
b. organ system, organ, tissue, cell
c. tissue, organ, organ system,
d. cell, tissue, organ, organ

____ 36. Plant cells have a large membrane-bound space in which water, waste products, and nutrients are stored. This is known as the
a. mitochondria
b. central vacuole
c. chloroplasts
d. Golgi apparatus

____ 37. During osmosis
a. water moves from a concentrated solution to a dilute
b. solutes move from a concentrated solution to a dilute
c. water moves from a dilute solution to a concentrated

d. solutes move from a dilute solution to a concentrated

____ 38. When a plant cell is surrounded by a hypotonic solution, water enters the cell and the plant cell becomes

a. plasmolysed	c. normal
b. turgid	d. crenated

Short Answer

39. Compare and contrast prokaryotic and eukaryotic cells. Include at least two similarities and two differences.

40. Provide one example of a specialized cell in a multicellular organism. Describe how the cell you chose is specialized to carry out its function.

41. Compare and contrast animal and plant cells. Include at least two similarities and two differences.

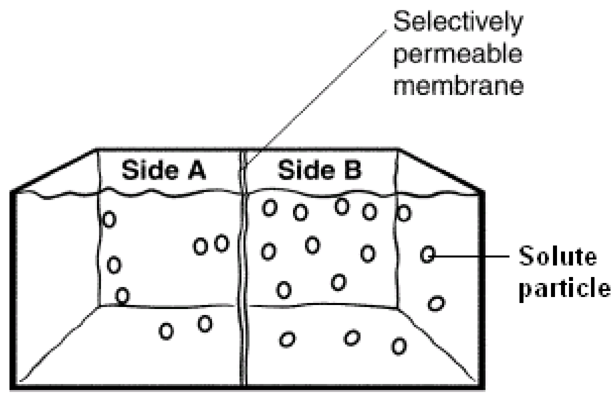
42. Where in the human body would you find cells with a large number of mitochondria? Why?

43. List three ways that substances can pass across a membrane and for each one state whether it is active or passive.

44. What are two differences between active transport and diffusion?

45. If a red blood cell is placed in a saltwater solution that is hypertonic compare to the red blood cell, what will happen to the red blood cell in terms of osmosis?

A student put together the experimental setup shown below. The selectively permeable membrane is permeable to water, but not the solute shown.



46. **Interpret Visuals** Describe the experimental setup shown in the figure above.

47. **Compare and Contrast** How does the solution on Side A of the apparatus shown in the figure above differ from the solution on Side B?

48. **Predict** Look at the figure above. Describe the movement of water in the experimental setup. What will happen to the concentration of water over time?

49. **Predict** What will the apparatus shown in the figure above look like when equilibrium is reached?

50. **Predict** Once equilibrium is reached in the apparatus shown in the figure above, will the water molecules continue to move? Explain your answer.

APPENDIX C

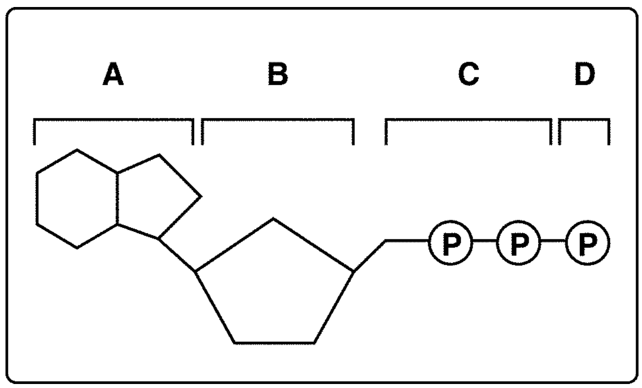
BIOENERGETICS TEST

Bioenergetics Test

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. What are the three parts of an ATP molecule?
a. adenine, thylakoid, and a phosphate
b. stroma, grana, and chlorophyll
c. adenine, ribose, and three phosphate
d. NADH, NADPH, and $FADH_2$

____ 2. Energy is released from ATP when
a. a phosphate group is added.
b. adenine bonds to ribose.
c. ATP is exposed to sunlight.
d. a phosphate group is



____ 3. Which structures shown in the figure above make up an ATP molecule?
a. A and B
b. A, B, and C
c. A, B, C, and D
d. C and D

____ 4. Organisms, such as plants, that make their own food are called
a. autotrophs. b. heterotrophs. c. thylakoids. d. pigments.

____ 5. Organisms that cannot make their own food and must obtain energy from external sources are called
a. autotrophs. b. heterotrophs. c. thylakoids. d. plants.

____ 6. Which of the following organisms makes its own food using light energy from the sun?
a. mushroom b. amoeba c. leopard d. oak tree

____ 7. Which of the following organisms is a heterotroph?

a. mushroom b. alga c. wheat d. sunflower

____ 8. What happens during photosynthesis?

a. Heterotrophs consume ATP.
b. Heterotrophs produce ATP.
c. Autotrophs consume
d. Autotrophs produce

____ 9. Plants get the energy they need for photosynthesis by absorbing

a. high-energy sugars.
b. chlorophyll *a*.
c. chlorophyll *b*.
d. sunlight.

____ 10. Most plants appear green because chlorophyll

a. absorbs green light.
b. absorbs violet light.
c. does not absorb green
d. does not absorb violet

____ 11. If carbon dioxide is completely removed from a plant's environment, what would you expect to happen to the plant's production of high-energy sugars?

a. More sugars will be produced.
b. No sugars will be produced.
c. The same number of sugars will be produced but without carbon
d. Fewer sugars will be produced at first, but then the plant will

____ 12. Which of the following is NOT a stage of cellular respiration?

a. fermentation
b. electron transport chain
c. glycolysis
d. Krebs cycle

____ 13. Which of the following is the correct sequence of events in cellular respiration?

a. Glycolysis, fermentation, Krebs cycle
b. Krebs cycle, electron transport, glycolysis
c. Glycolysis, Krebs cycle, electron transport chain
d. Krebs cycle, glycolysis, electron transport chain

____ 14. What are the reactants in the equation for cellular respiration?

a. oxygen and lactic acid
b. carbon dioxide and water
c. glucose and oxygen
d. water and glucose

____ 15. Which of these is a product of cellular respiration?

a. oxygen b. water c. glucose d. lactic acid

____ 16. Cellular respiration is called an aerobic process because it requires

a. light. b. exercise. c. oxygen. d. glucose.

____ 17. Which of the following is one of the ways that cellular respiration and photosynthesis are opposite processes?

a. Photosynthesis releases energy, and cellular respiration stores energy.
b. Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back.
c. Photosynthesis removes oxygen from the atmosphere, and cellular respiration puts it back.
d. Photosynthesis consumes glucose, and cellular respiration produces glucose.

____ 18. Photosynthesis is to chloroplasts as cellular respiration is to

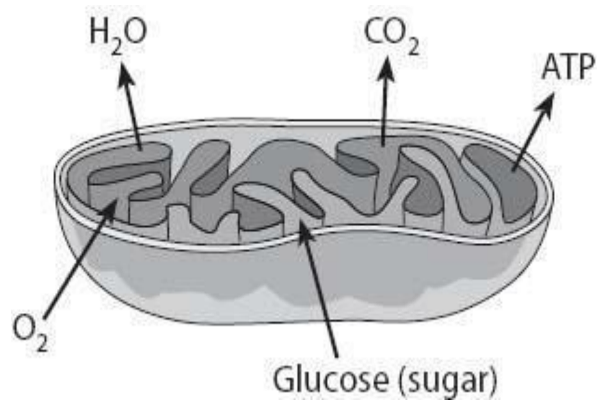
a. chloroplasts. b. cytoplasm. c. mitochondria d. nuclei.

____ 19. Unlike photosynthesis, cellular respiration occurs in

a. animal cells only.
b. plant cells only.
c. prokaryotic cells only.
d. all eukaryotic cells.

____ 20. Which of the following are reactants for cellular respiration and products for photosynthesis?

a. energy and water.
b. glucose and oxygen.
c. glucose and carbon
d. carbon dioxide and water.



____ 21. What process do the arrows for oxygen going in and water coming out represent in the diagram of the mitochondria above?

a. electron transport chain
b. fermentation
c. glycolysis
d. the Krebs cycle

____ 22. Cellular respiration uses 1 molecule of glucose to produce approximately

a. 2 ATP molecules.
b. 4 ATP molecules.
c. 32 ATP molecules.
d. 36 ATP molecules.

____ 23. Lactic acid fermentation occurs in

a. bread dough.
b. any environment containing oxygen.
c. muscle cells.
d. mitochondria.

____ 24. The two main types of fermentation are called

a. alcoholic and aerobic.
b. aerobic and anaerobic.
c. alcoholic and lactic acid.
d. lactic acid and

____ 25. In most plants, which organs are adapted to capture sunlight for photosynthesis?

a. roots
b. stems
c. leaves
d. flowers

____ 26. If some of the xylem of a young oak tree were destroyed, it would most likely interfere with the tree's ability to

a. conduct sugars to the roots.
b. absorb sunlight.
c. absorb nutrients from the
d. conduct water to the leaves.

____ 27. Vascular tissue in plants consists of

a. meristems.
b. xylem and phloem.
c. parenchyma and
d. epidermis.

____ 28. Many cacti, such as saguaros and barrel cacti, have large stems and no leaves. What function of leaves is taken on by the stems of such cacti?

a. They produce food by photosynthesis.
b. They absorb water and nutrients from the
c. They transport materials throughout the
d. They store excess water.

____ 29. Oxygen and carbon dioxide move in and out of a leaf through the

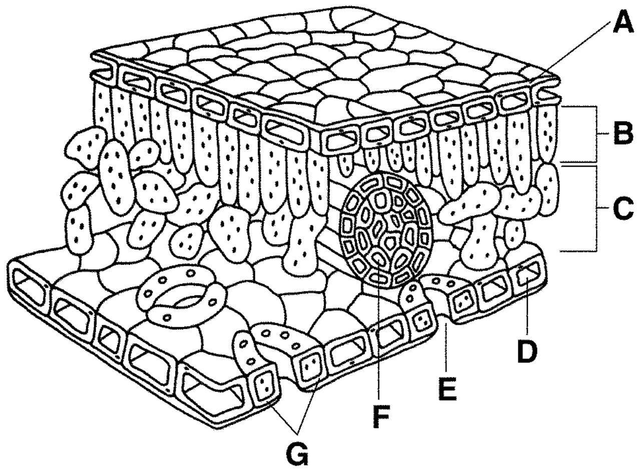
a. palisade mesophyll.
b. guard cells.
c. phloem.
d. stomata.

____ 30. Most of the photosynthesis in plants takes place in the

a. mesophyll.
b. guard cells.
c. stomata.
d xylem.

____ 31. The flat structure of a leaf blade enables its function as a photosynthetic organ by

a. decreasing the loss of oxygen into the atmosphere.
b. increasing the absorption of nutrients from soil.
c. protecting the rest of the plant from water loss due to
d. exposing a greater surface area to capture energy from



_____ 32. Look at diagram of the leaf above. Which letters indicate cells in which a large number of chloroplasts would likely be found?

a. A and D b. B and C c. F and G d. G and E

_____ 33. In the diagram of the leaf above, which letter points to the structure through which water is lost during transpiration?

a. A b. D c. E d. F

_____ 34. In many plants, stomata are found only on the lower surface of the leaf. The most likely explanation for this fact is that

a. photosynthesis only occurs in the spongy mesophyll near the bottom of the leaf.
b. stomata are closer to vascular bundles that bring water into the leaf.
c. gravity plays a role in gas exchange.
d. water loss would be less on the shaded lower surface than in direct sun.

_____ 35. When a plant moves sugars from its leaves to its roots, this occurs in vascular tissue known as

a. phloem. b. xylem. c. cuticle. d. root hairs.

_____ 36. Which of the following lists components needed for photosynthesis to occur?

a. oxygen, carbon dioxide, and sugars
b. light energy and water
c. water and carbon dioxide
d. light energy, carbon dioxide, and water

____ 37. Which of the following structures help to conserve water inside a leaf?

a. air spaces and stomata
b. stomata and cuticle
c. cuticle and spongy layer
d. spongy layer and air

____ 38. Of the following stages of cellular respiration, which produces the most ATP?

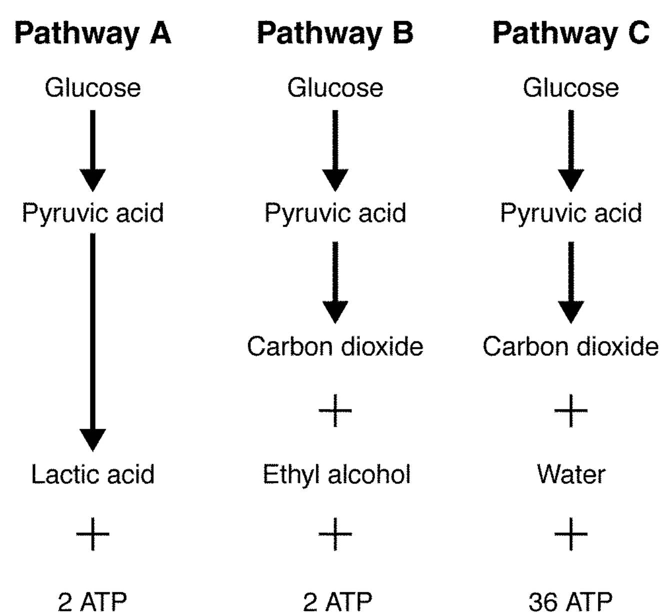
a. Glycolysis
b. Conversion of pyruvic acid to CO_2
c. Electron transport chain
d. All of these produce equal amounts of ATP.

____ 39. What reactant of photosynthesis is NOT recycled and must be constantly available?

a. water
b. glucose
c. carbon dioxide
d. sunlight energy

Short Answer

40. Write the overall equation for photosynthesis in both symbols and words.

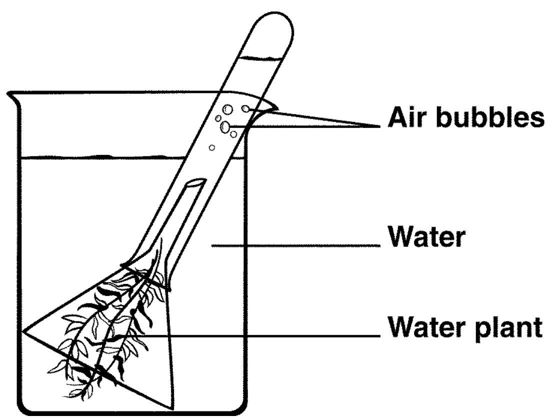


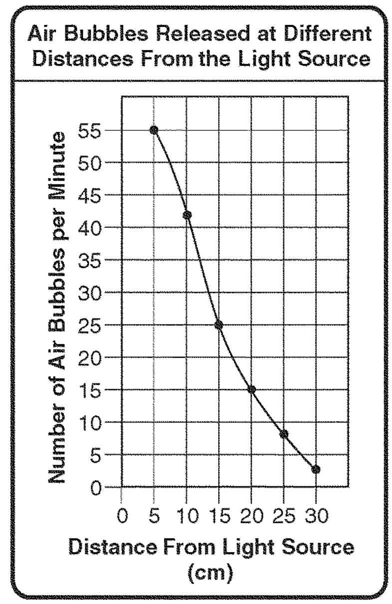
41. Based on the figure above, which pathway is most efficient at producing energy for a cell? Explain your answer.

42. Compare and contrast the amount of energy available to cells resulting from aerobic respiration and anaerobic respiration. Include one similarity and one

difference in your response.

A student prepared two beakers with identical sprigs of a water plant as shown below. She placed one beaker in the shade and the other beaker beside a fluorescent lamp. She then systematically changed the distance from the beaker to the lamp. She counted the bubbles given off by the plants in each beaker. Shown here is the graph of the data for the beaker she placed beside the lamp.

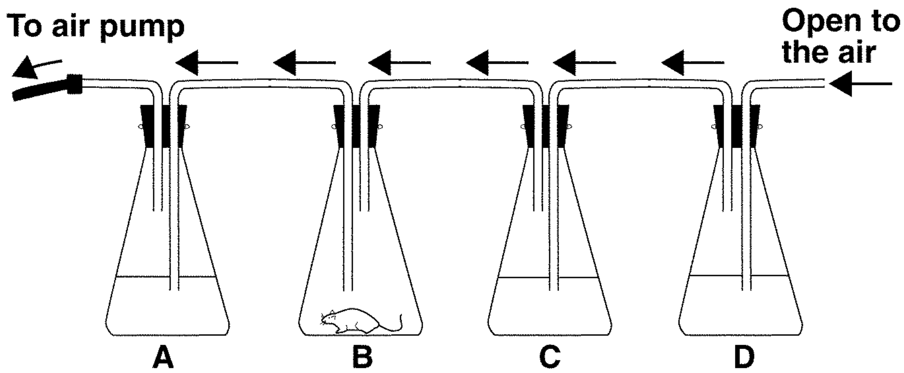




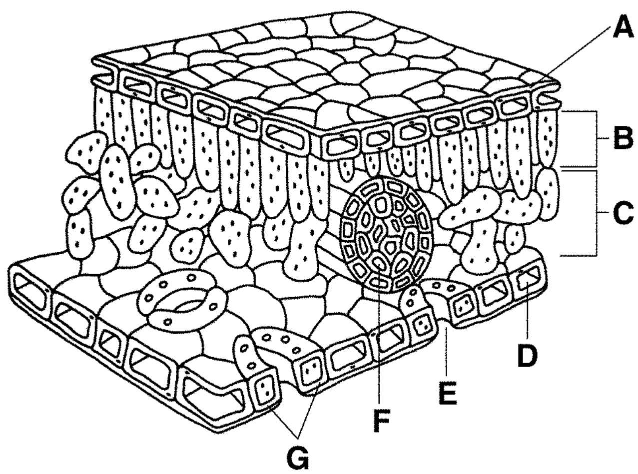
43. **Apply Concepts** Look at the figure above. If the student later tested the bubbles collected in the test tube, what would she find they are made of? How do you know?

44. **Analyze Data** Look at the graph above. What do the student's data show?

A scientist set up a respiration chamber as shown below. She placed a mouse in flask B. Into flasks A, C, and D, she poured distilled water mixed with the acid-base indicator phenolphthalein. In the presence of CO_2, phenolphthalein turns from pink to clear. She allowed the mouse to stay in the chamber for about an hour.



45. **Infer** Write the equation for cellular respiration. Based on this equation and the setup shown in the figure above, what substance(s) would you expect the mouse in flask B to give off?
46. **Interpret Visuals** Based on the figure above, how will the scientist be able to detect whether the mouse is carrying out cellular respiration?



47. **Use Models** Which four structures in the diagram of the leaf above protect the leaf from drying out? Identify the structures.

48. **Interpret Visuals** In the diagram of the leaf above, which letter represents a structure whose tissues lack chlorophyll? What is the structure called?

49. **Interpret Visuals** Are the stomata in the leaf in the diagram above open or closed? Identify the letter of the stoma.

50. **Interpret Visuals** In the diagram of the leaf above, what is structure F? What two types of tissues make up this structure?

APPENDIX D

REPRODUCTION, GROWTH AND DEVELOPMENT TEST

Reproduction, Growth and Development Test

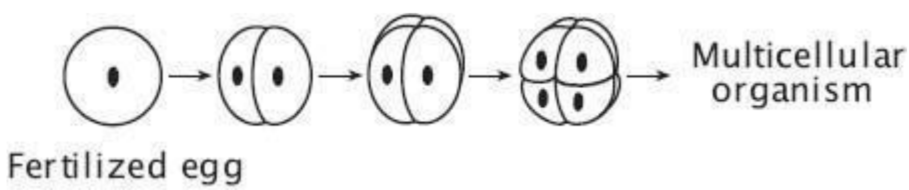
Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. As a cell becomes larger, its
a. volume increases faster than its surface area.
b. surface area increases faster than its volume.
c. volume increases, but its surface area stays the
d. surface area stays the same, but its volume

____ 2. Compared to small cells, large cells have more trouble
a. dividing.
b. producing daughter cells.
c. storing needed materials and waste products.
d. moving needed materials in and waste products

____ 3. Which of the following happens when a cell divides?
a. The cell's volume increases.
b. It becomes more difficult for the cell to get rid of wastes.
c. Each daughter cell receives its own copy of the parent cell's DNA.
d. It becomes more difficult for the cell to get enough oxygen and

____ 4. An advantage of sexual reproduction over asexual reproduction is that sexual reproduction…
a. takes less time
b. requires more time
c. provides genetic diversity
d. produces identical



____ 5. A multicellular organism begins life as a single cell—a fertilized egg with a complete set of chromosomes. The picture in the figure above shows how the cell divides to become two cells, then four cells, eight cells, and so on. Which of the following statements best describes what happens during this process?
a. Chromosomes are duplicated before cell division so that each new daughter cell has a complete set.
b. Chromosomes are divided evenly during cell division so that each new daughter cell has an equal share of the original set.
c. Chromosomes are stored in the original cell to direct the division of all daughter cells, which do not have their own chromosomes.

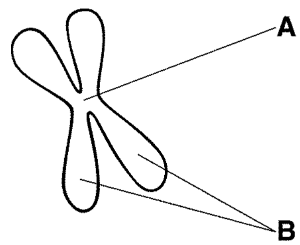
d. Chromosomes are randomly distributed during cell division so that some new cells have partial sets while others have complete sets.

____ 6. Which pair includes a phase of the cell cycle and a cellular process that occurs during that phase?

a. G_1 phase, DNA replication
b. G_2 phase, preparation for mitosis
c. S phase, cell division
d. M phase, cell growth

____ 7. When during the cell cycle is a cell's DNA replicated?

a. G_1 phase b. G_2 phase c. S phase d. M phase



____ 8. The structure labeled A in the figure above is called the

a. centromere.
b. centriole.
c. sister chromatid.
d. spindle.

____ 9. The structures labeled B in the figure above are called

a. centromeres.
b. centrioles.
c. sister chromatids.
d. spindles.

____ 10. During which phase of mitosis do the chromosomes line up along the middle of the dividing cell?

a. prophase b. telophase c. metaphase d. anaphase

____ 11. What is the role of the spindle fibers during mitosis?

a. They help separate the chromosomes.
b. They break down the nuclear
c. They duplicate the DNA.
d. They make the chromosomes visible.

_____ 12. During normal mitotic cell division, a parent cell that has four chromosomes will produce two daughter cells, each containing

a. two chromosomes.
b. four chromosomes.
c. eight chromosomes.
d. sixteen chromosomes.

_____ 13. Cancer is a disorder in which some cells have lost the ability to control their

a. size.
b. spindle fibers.
c. growth rate.
d. surface area.

_____ 14. Cancer cells form masses of cells called

a. tumors.
b. cyclins.
c. growth factors.
d. p53.

_____ 15. During early development, all cells in the embryo of a multicellular organism are identical. Later on in development, the cells will become specialized through a process called

a. apoptosis. b. cytokinesis. c. differentiation d. interphase

_____ 16. Why are stem cells important?

a. They have specialized DNA.
b. They are incapable of becoming cancer cells.
c. They have the potential to undergo cell division.
d. They have the potential to develop into other cell

_____ 17. Which of the following is a possible future benefit of stem cell research?

a. developing a vaccine for cancer
b. reversing damage from a heart attack
c. generating embryos from nonliving
d. increasing a person's intelligence

_____ 18. If an organism's diploid number is 12, its haploid number is

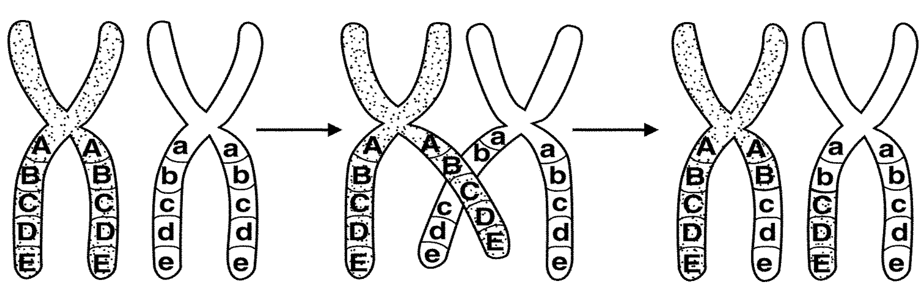
a. 12. b. 6. c. 24. d. 3.

_____ 19. Gametes have

a. homologous chromosomes.
b. twice the number of chromosomes found in body
c. two sets of chromosomes.
d. one allele for each gene.

_____ 20. Gametes are produced by the process of

a. mitosis. b. meiosis. c. crossing-over. d. replication.



____ 21. What is shown in the figure above?
a. independent assortment
b. anaphase I of meiosis
c. crossing-over
d. replication

____ 22. Chromosomes form tetrads during
a. prophase I of meiosis.
b. metaphase I of meiosis.
c. interphase.
d. anaphase II of meiosis.

____ 23. Unlike mitosis, meiosis results in the formation of
a. diploid cells.
b. haploid cells.
c. 2N daughter cells.
d. body cells.

____ 24. What is formed at the end of meiosis?
a. two genetically identical cells
b. four genetically different cells
c. four genetically identical cells
d. two genetically different cells

____ 25. At the end of meiosis, there are
a. two haploid daughter cells.
b. four haploid daughter cells.
c. two diploid daughter cells.
d. four diploid daughter

____ 26. Which of the following assort independently?
a. chromosomes
b. linked genes
c. multiple alleles
d. codominant alleles

_____ 27. Consider two spherical cells. One is 150 micrometers while the other has a diameter of 300 micrometers.
Which has the greater surface area-to-volume ratio?
a. the smaller diameter cell
b. the larger diameter cell
c. they have the same surface area-to-volume

____ 28. Which of the following best describes why cells do not indefinitely continue to increase in size?
a. Cells do not have enough DNA to allow them to grow very large.
b. Cells have only enough resources to grow to a certain size and then they have to stop growing.
c. As a cell becomes larger, their surface area-to-volume ratio decreases and they are no longer able to function properly or efficiently.
d. The size of the cell is directly related to the size of the organism, so smaller organisms have smaller cells and larger organisms have larger cells.

_____ 29. Most normal cells in an adult organism are in which phase of the cell cycle?
a. G_1 b. G_2 c. Mitosis d. Synthesis

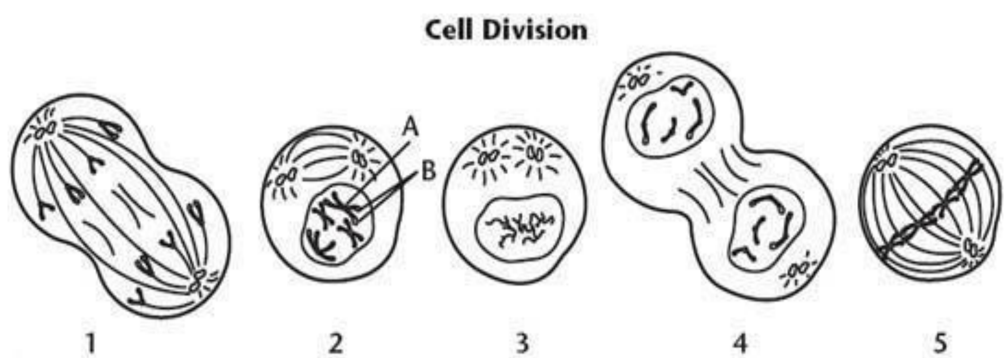
_____ 30. Which of the following is true concerning mitosis and the cell cycle?
a. Mitosis occurs immediately before the S
b. Mitosis occurs immediately after cytokinesis.
c. Mitosis occurs after G_2 and before
d. Mitosis occurs in between G_1 and G_2.

_____ 31. The phases of mitosis in the correct order are
a. prophase, telophase, anaphase, and metaphase
b. prophase, metaphase, anaphase, and telophase
c. telophase, anaphase, prophase, and metaphase
d. metaphase, anaphase, prophase, and telophase

_____ 32. If an organism contains 10 chromosomes in its body cells, how many chromosomes will be in the mature sperm cells?
a. 5 b. 10 c. 20 d. 40

_____ 33. If an organism contains 10 chromosomes in its body cells, how many chromosomes will be in the zygote?
a. 5 b. 10 c. 20 d. 40

Short Answer



34. Identify each phase of mitosis shown in the figure above and the order in which they occur.

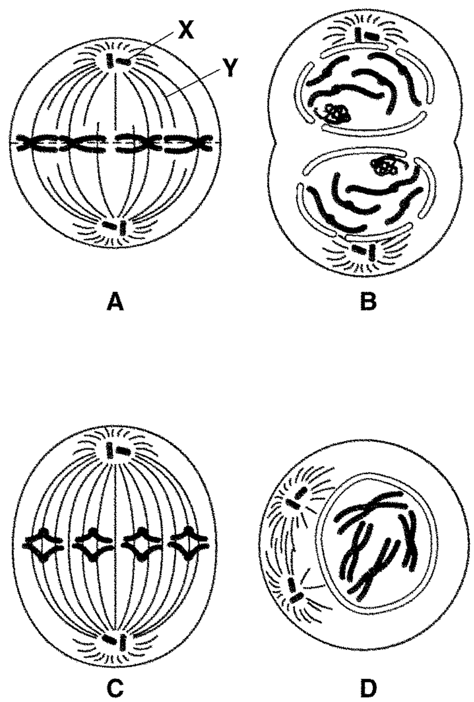
35. How are embryonic stem cells different from adult stem cells?

36. What are the only kinds of cells that undergo meiosis?

37. Put the four stages of the cell cycle in order: mitosis, G_2, G_1, synthesis.

38. Describe two situations in human life when mitosis would be critically important.

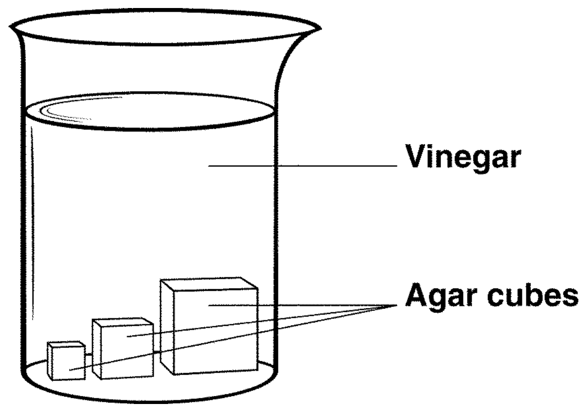
39. Meiosis and sexual reproduction each lead to variation in the genetic makeup of every person. Identify two ways during meiosis that contribute to this genetic variation.



40. **Infer** What is the chromosome number of the cell shown in the figure above?

41. **Predict** After the steps shown in the figure above are arranged in the correct order, what would a diagram of the next step show?

A student placed three cubes of agar that contained the indicator phenolphthalein in a beaker of vinegar. The sides of the cubes were the following lengths: 3 cm, 2 cm, and 1 cm. In the presence of an acid, such as vinegar, phenolphthalein turns from pink to clear. After 10 minutes, the student cut each cube open and measured the distance that the vinegar had diffused into each cube. She then started to complete the data table.



Comparison of Agar Cubes

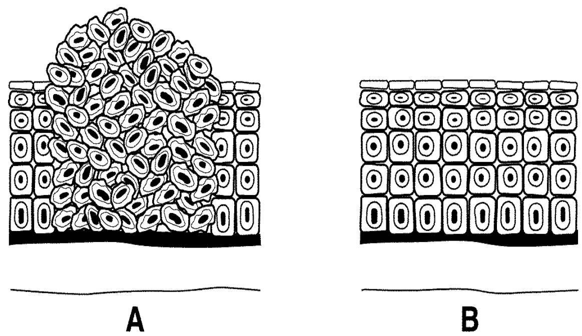
Cube Size (length in cm)	Surface Area (cm^2)	Volume (cm^3)	Ratio of Surface Area to Volume	Depth of Diffusion (mm)	Time (min.)
3	**54**	**27**			**10**
2					**10**
1	**6**	**1**			**10**

42. **Calculate** Look at the data table in figure above. What are the surface area, volume, and ratio of surface area to volume for the cube that is 2 cm in length?

43. **Compare and Contrast** Compare the cubes in the figure above with respect to their sizes and their ratios of surface area to volume.

44. **Infer** Look at the experimental setup in the figure above. How will the student know how far the vinegar has diffused into each cube?

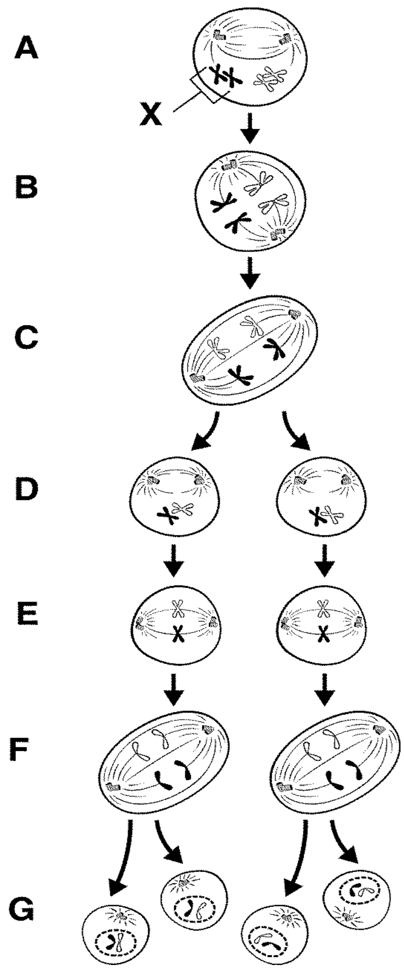
45. **Predict** Examine the figure above. In which cube will the vinegar take the longest time to diffuse into the center? In which tube will the vinegar take the shortest time to diffuse into the center?



46. **Interpret Visuals** Look at the figure above. Which diagram shows cancer cells? How do you know?

47. **Compare and Contrast** Explain how cancer cells are different from normal cells. Then, relate these characteristics to the diagram in the figure above that shows cancer cells.

48. **Predict** Look at the cancer cells shown in the figure above. What can happen if these cells are left untreated?



49. **Interpret Visuals** In the figure above, what is the structure labeled X in stage A?

50. **Infer** If the stages shown in the figure above were taking place in a female animal, how many eggs would generally result from stage G? Explain your answer.

APPENDIX E

ECOLOGY TEST

Ecology Test

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. Which of the following descriptions about the organization of an ecosystem is correct?

a. Communities make up species, which make up populations.

b. Populations make up species, which make up communities.

c. Species make up communities, which make up populations.

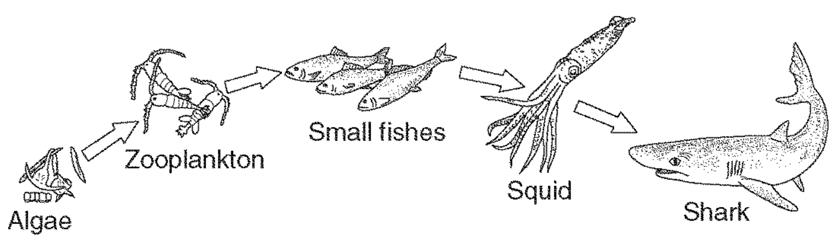
d. Species make up populations, which make up communities.

____ 2. The simplest grouping of more than one kind of organism in the biosphere is

a. a population.
b. a community.
c. an ecosystem.
d. a species.

____ 3. The lowest level of environmental complexity that includes living and nonliving factors is the

a. biome.
b. community.
c. ecosystem.
d. biosphere.



____ 4. The algae at the beginning of the food chain in the figure above are

a. primary consumers.
b. decomposers.
c. primary producers.
d. heterotrophs.

____ 5. How do most primary producers make their own food?

a. by using light energy to make carbohydrates
b. by using chemical energy to make carbohydrates
c. by changing water into carbon dioxide
d. by breaking down remains to make carbon

____ 6. Corn planted in a field that has been previously planted with legumes and then plowed under is likely to be

a. less productive because legumes remove phosphorus from the soil.
b. more productive because bacteria living on the roots of legumes fix nitrogen in the soil.
c. more productive because nitrogen-fixing bacteria help to keep away pests.
d. less productive because the legumes have already taken all the nitrogen, carbon, and phosphorus from the soil.

_____ 7. The total amount of living tissue within a given trophic level is called the

a. organic mass. b. trophic mass. c. energy mass. d. biomass.

____ 8. What is an ecological model of the relationships that form a network of complex feeding interactions among organisms in a community from producers to decomposers?

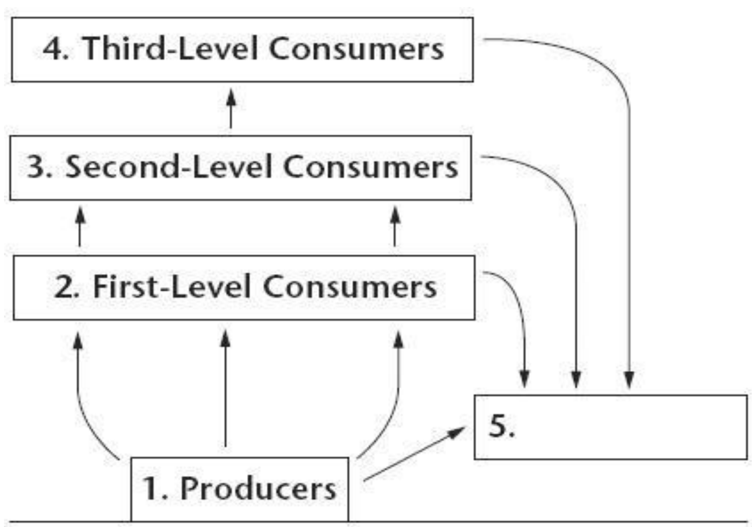
a. food web b. ecosystem c. food chain d. population

____ 9. What is the term for each step in the transfer of energy and matter within a food web?

a. energy path
b. food chain
c. trophic level
d. food pyramid

____ 10. A bird stalks, kills, and then eats an insect. Based on its behavior, which pair of ecological terms describes the bird?

a. herbivore, decomposer
b. producer, heterotroph
c. carnivore, consumer
d. autotroph, herbivore



____ 11. What goes in Box 5 of the food web in the figure above?
a. herbivores b.scavengers c. carnivores d.decomposers

____ 12. What are the three kinds of ecological pyramids?
a. producer, consumer, and decomposer
b. energy, nutrient, and trophic
c. energy, biomass, and numbers
d. biotic, abiotic, and nutrient

____ 13. Only 10 percent of the energy stored in an organism can be passed on to the next trophic level. Of the remaining energy, some is used for the organism's life processes, and the rest is
a. used in reproduction.
b. stored as body tissue.
c. stored as fat.
d. eliminated as heat.

____ 14. Matter can recycle through the biosphere because
a. matter does not change into new compounds.
b. matter is assembled into chemical compounds.
c. biological systems do not use up matter, they transform it.
d. biological systems use only carbon, oxygen, hydrogen, and

____ 15. The repeated movement of water between Earth's surface and the atmosphere is called
a. the water cycle.
b. the condensation cycle.
c. precipitation.
d. evaporation.

____ 16. Carbon cycles through the biosphere in all of the following processes EXCEPT
a. photosynthesis.
b. transpiration.
c. burning of fossil fuels.
d. decomposition of plants and

____ 17. Which part of the water cycle is a biological process?
a. transpiration b. runoff c. precipitation d. condensation

____ 18. Nitrogen fixation is carried out primarily by
a. humans. b. plants. c. bacteria. d. consumers.

____ 19. Which of the following has a direct role in the nitrogen cycle?
a. bacteria
b. legumes
c. decomposers
d. all of the above

____ 20. Organisms need nutrients in order to

a. utilize hydrogen and oxygen.

b. carry out essential life functions.

c. recycle chemical compounds.

d. carry out nitrogen fixation.

____ 21. The movements of energy and nutrients through living systems are different because

a. energy flows in one direction, and nutrients recycle.
b. energy is limited in the biosphere, and nutrients are always
c. nutrients flow in one direction, and energy recycles.
d. energy forms chemical compounds, and nutrients are lost as heat.

____ 22. Biogeochemical cycling ensures that

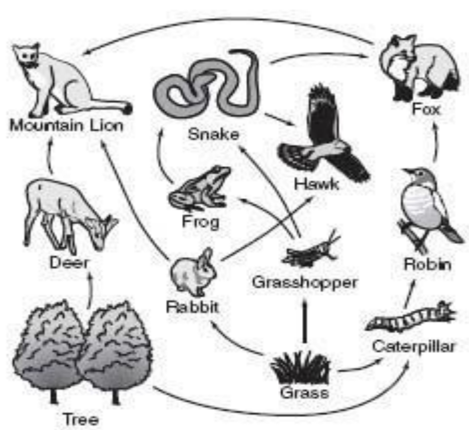
a. human activity will have no effect on elements, chemical compounds, and other forms of matter.
b. living organisms will not become limited in any one nutrient.
c. nutrients will be circulated throughout the biosphere.
d. many nutrients will not reach toxic concentrations in the biosphere.

____ 23. Which is a biotic factor that affects the size of a population in a specific ecosystem?

a. average temperature of the ecosystem
b. type of soil in the ecosystem
c. number and kinds of predators in the
d. concentration of oxygen in the ecosystem

____ 24. What is at the base of all ecological pyramids?

a. consumers b. decomposers c. producers d. scavengers



_____ 25. Which of the following is a food chain in the food web shown in the figure above?

a. tree, rabbit, hawk, snake
b. grass, grasshopper, snake, hawk
c. grass, caterpillar, robin, hawk
d. tree, deer, mountain lion, fox

_____ 26. The greenhouse effect is

a. something that has only occurred for the last 50 years.
b. a natural phenomenon that maintains Earth's temperature range.
c. the result of the differences in the angle of the sun's rays.
d. an unnatural phenomenon that causes heat energy to be radiated back into the atmosphere.

_____ 27. A wolf pack hunts, kills, and feeds on a moose. In this interaction, the wolves are

a. hosts.
b. prey.
c. mutualists.
d. predators.

_____ 28. A symbiotic relationship in which both species benefit is

a. commensalism.
b. mutualism.
c. predation.
d. parasitism.

_____ 29. A symbiotic relationship in which one organism is harmed and the other benefits is

a. mutualism.
b. parasitism.
c. commensalism.
d. predation.

_____ 30. How is parasitism different from commensalism?

a. Both organisms benefit in parasitism and only one organism benefits in commensalism.
b. One organism benefits in parasitism and no organisms benefit in commensalism.
c. One organism is harmed in parasitism and both organisms are harmed in commensalism.
d. One organism is harmed in parasitism and no organisms are harmed in commensalism.

_____ 31. There are 150 Saguaro cactus plants per square kilometer in a certain area of Arizona desert. To which population characteristic does this information refer?

a. growth rate
b. geographic range
c. age structure
d. population density

_____ 32. What does the range of a population tell you that density does not?

a. the number that live in an area
b. the areas inhabited by a population
c. the births per unit area
d. the deaths per unit area

_____ 33. Which of the following is NOT one of the factors that play a role in population growth rate?

a. immigration b. death rate c. emigration d. demography

_____ 34. The movement of organisms into a range is called

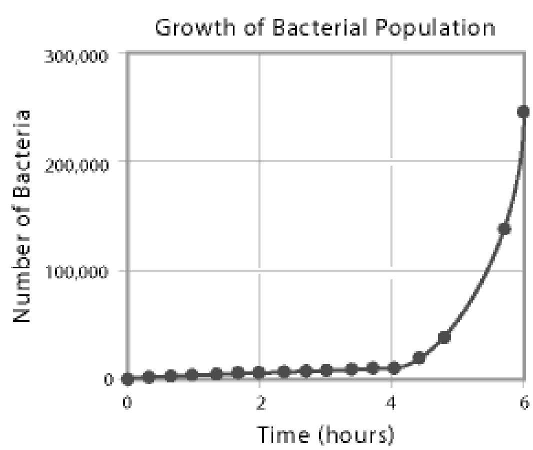
a. immigration.
b. emigration.
c. population shift.
d. carrying capacity.

_____ 35. Which of the following describes a population as its size decreases?

a. The birthrate and the death rate remain the same.
b. The death rate becomes lower than the birthrate.
c. The death rate stays the same and the birthrate
d. The death rate becomes higher than the birthrate.

_____ 36. Which are two ways a population can decrease in size?

a. immigration and emigration
b. increased death rate and immigration
c. decreased birthrate and emigration
d. emigration and increased birthrate



_____ 37. The graph in the figure above shows the growth of a bacterial population. Which of the following correctly describes the growth curve?

a. logistic b. limiting c. demographic d. exponential

_____ 38. Suppose that a species of toads is introduced into a new environment in an attempt to reduce the population of insects. The toad has no natural predators in the new environment. The toad population would most likely
a. increase exponentially.
b. increase logistically.
c. decrease rapidly and die out.
d. remain the same.

_____ 39. During some kinds of population growth, the size of each generation of offspring is larger than the generation before it. So, as the population gets larger, it grows more quickly. This situation is called
a. logistic growth.
b. growth density.
c. exponential growth.
d. multiple growth.

_____ 40. Which factor might NOT contribute to an exponential growth rate in a given population?
a. lower death rates
b. higher birthrates
c. less competition
d. reduced resources

_____ 41. The various growth phases through which most populations go are represented on
a. a logistic growth curve.
b. an exponential growth curve.
c. a normal curve.
d. a population curve.

_____ 42. As resources in a population become less available, the population
a. declines rapidly.
b. increases rapidly.
c. reaches carrying capacity.
d. enters a phase of exponential growth.

_____ 43. When the exponential phase of a logistic growth curve of a population ceases,
a. the size of the population drops.
b. the size of the population stays the
c. population growth begins to slow down.
d. population growth begins to speed up.

_____ 44. Something that controls the growth or size of a population is a
a. carrying capacity.
b. limiting nutrient.
c. limiting factor.
d. growth factor.

____ 45. Which will reduce competition within a species' population?

a. fewer individuals
b. higher birthrate
c. fewer resources
d. higher population density

____ 46. If a population grows larger than the carrying capacity of the environment, the

a. death rate may rise.
b. birthrate may rise.
c. death rate must fall.
d. birthrate must fall.

____ 47. Water lilies do not grow in desert sand because water availability to these plants in a desert is

a. a limiting factor.
b. the carrying capacity.
c. a competition factor.
d. the logistic growth curve.

____ 48. A disease resulting in the deaths of one third of a dense population of bats in a cave would be a

a. density-dependent limiting factor.
b. result of exponential growth.
c. density-independent limiting factor.
d. nutrient-limiting factor.

____ 49. Which of the following is a density-independent limiting factor?

a. a struggle for food, water, space, sunlight
b. predator/prey relationships
c. the eruption of a volcano
d. parasitism and disease

____ 50. Inter-specific competition is competition among

a. organisms from one species only.
b. organisms from two or more different
c. predators and prey.
d. parasite and host.

____ 51. One of the important tasks of the nitrogen cycle is to change atmospheric nitrogen (N_2) to the form of nitrogen that plants can use. What is the usable form of nitrogen for plants?

a. ammonia
b. nitrates
c. nitrites
d. all of these can be used by plants.

_____ 52. Why must nutrients such as carbon, nitrogen, and water be constantly recycled?

a. Life would not be properly sustained without them being recycled.

b. Nutrients would be locked in dead bodies and wastes and would not be available to organisms in a usable form.

c. Since these are cycles are "closed systems," no more nutrients will be added to them.

d. All of these are why the nutrients are constantly recycled.

_____ 53. Exponential growth is represented by a

a. J curve b. K curve c. S curve d. Y curve

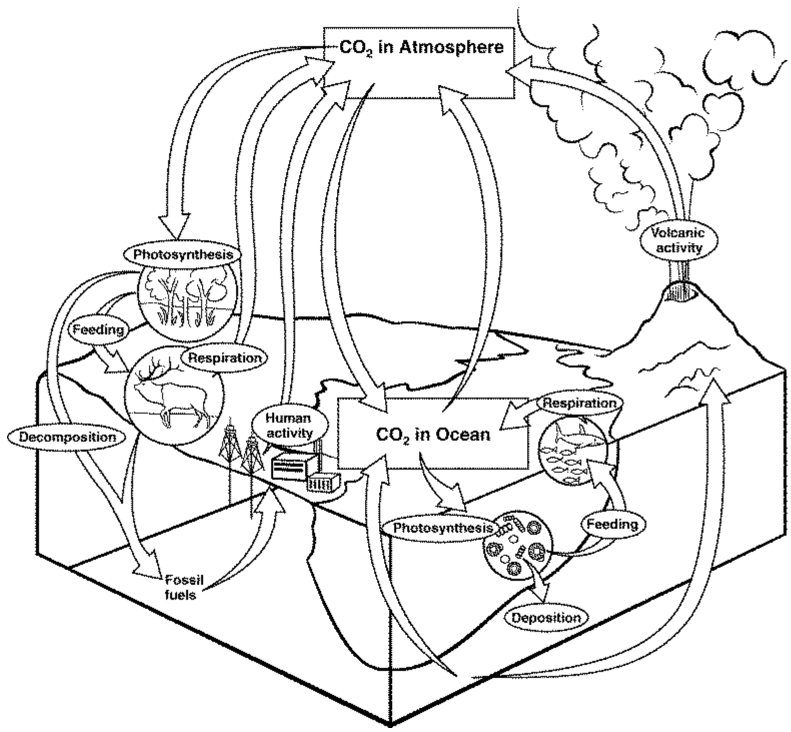
Short Answer

54. Describe the flow of energy to a third-level consumer if the producers provide 1500 calories of energy to the first-level consumers.

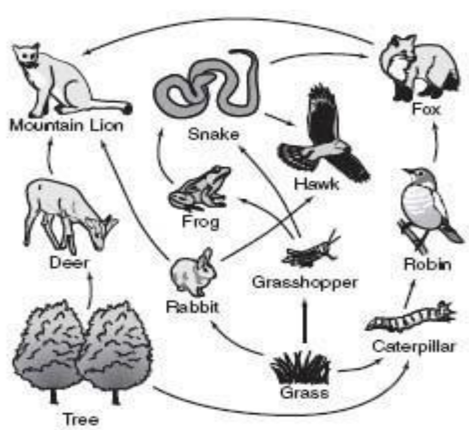
55. How is intraspecific competition different from interspecific competition?

56. Using an example, explain why a clumped population distribution can be advantageous.

57. What term is used to describe the maximum numbers of individuals the environment can support at a given time?



58. **Interpret Visuals** Which steps in the figure above show the carbon cycle passing through living systems? Which step shows carbon passing through a geological process?

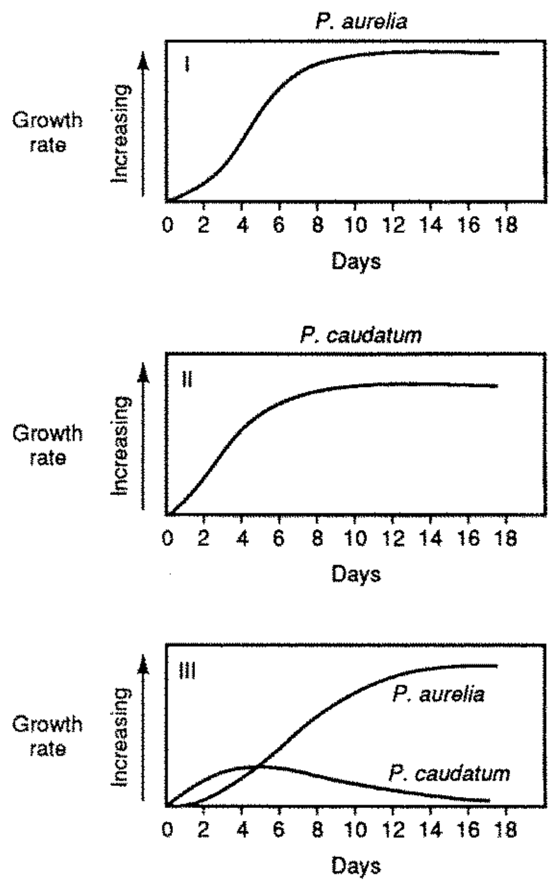


59. **Draw Conclusions** Are there any omnivores in the figure above? Explain your answer.

60. **Draw Conclusions** Which species would be MOST affected if a disease killed off most of the trees in the ecosystem shown in the figure above? What other

species might be affected? Explain your answers.

Graph I shows the growth curve for a culture of *Paramecium aurelia*. Graph II shows the growth curve for a culture of *Paramecium caudatum*, a larger species. Graph III shows the growth curves of both species when they are grown together.



61. **Interpret Graphs** According to the figure above, which species has the greatest initial growth rate when they are grown in separate cultures?

62. **Observe** What type of population growth curve can be observed in Graphs I and II of the figure above?

63. **Draw Conclusions** What is the most likely reason why the population of *P. caudatum* decreased in Graph III in the figure above?

APPENDIX F

CELL STRUCTURE AND FUNCTION QUIZ

Cell Structure and Function Quiz

1. Which structure is NOT found in both prokaryotic and eukaryotic cells?
   a. DNA b. Ribosomes c. Cell membrane d. Mitochondria

2. Draw and label the major structures of a prokaryotic cell.

3. Compare and contrast prokaryotic and eukaryotic cells. Include at least three similarities and two differences.

4. Cells that actively produce proteins will contain large numbers of which organelles?
   a. Ribosomes b. Mitochondria c. Cilia d. Chloroplasts

5. Plant cells have a large membrane-bound space in which water, waste products, and nutrients are stored. This organelle is known as the….
   a. Mitochondria b. Central vacuole c. Chloroplastsd. Rough ER

6. All eukaryotic cells have…
   a. A covering called a membrane that surrounds the cell and controls what information and materials enter and leave it.
   b. An internal fluid that gives shape to the cell and supports the other structures within it.
   c. A central zone or nucleus that contains the cell's genetic material.
   d. All of the above.

7. List three organelles that plant cells have that are not found in animal cells.

8. Contrast plant and animal cells. Include at least three differences.

APPENDIX G

ATP AND PHOTOSYNTHESIS QUIZ

ATP & Photosynthesis Quiz

1. What are the three components of an ATP molecule?

2. Draw and label an ATP molecule. Indicate where the energy is stored in your drawing.

3. Which of the following lists the components needed for photosynthesis to take place.
   a. oxygen, carbon dioxide, and sugars
   b. light energy and water
   c. water and carbon dioxide
   d. light energy, carbon dioxide, and water

4. Which of the following structures help to conserve water inside a leaf?
   a. air spaces and stomata
   b. stomata and cuticle
   c. cuticle and spongy layer
   d. spongy layer and air spaces

5. What are the two reactions of photosynthesis?

6. Write out the chemical equation for photosynthesis in both words and molecular formulas. Identify the reactants and products in the chemical equation.

7. Describe the function of both the xylem and phloem. How do these vascular tissues connect to photosynthesis?

8. Which wavelengths of light (colors) are absorbed by chlorophyll? Which wavelengths of light (colors) are reflected by chlorophyll?

APPENDIX H

CELL SIZE AND CYCLE QUIZ

Cell Size and Cycle Quiz

1. Consider two spherical cells. One is 150 micrometers while the other has a diameter of 300 micrometers. Which cell has the greater surface area to volume ratio?

2. Which of the following best describes why cells do not indefinitely continue to increase in size?
   a. Cells do not have enough DNA to allow them to grow very large.
   b. Cells have only enough resources to grow a certain size and then they have to stop growing.
   c. As cells become larger, their surface area-to-volume ratio decreases and they are no longer able to function properly or efficiently.
   d. The size of the cell is directly related to the size of the organism, so smaller organisms have smaller cells and larger organisms have larger cells.

3. Summarize the reasons why very large cells are fairly rare among the multicellular eukaryotes.

4. Describe two problems cells face as they get larger.

5. Sketch and label the cell cycle. Put the phases of the cell cycle in order chronologically. Identify and describe each of the four main phases of the cell cycle.

6. Most normal cells in an adult organism are in which phase of the cell cycle?
   a. G_1 b. G_2 c. S d. M

7. Which phase of mitosis do the chromosomes line up in the middle of the cell?
   a. prophase b. metaphase c. anaphase d. telophase

8. What is the role of the spindle fibers in mitosis?

9. After mitosis occurs, what must take place for two daughter cells to be produced?

10. Describe two situations in human life when mitosis would be critically important.

APPENDIX I

ENERGY FLOW AND NUTRIENT CYCLES QUIZ

Energy Flow & Nutrient Cycles Quiz

1. What is the food eaten by an organism used for?
   a. Cellular respiration and waste production
   b. Waste production and biomass increase
   c. Cellular respiration, biomass increase, and waste production
   d. Biomass increase and waste production

2. All ecological pyramids have a base (bottom) level of
   a. Herbivores b. Omnivores c. Producers d. Consumers

3. What is the approximate amount of energy that is available for transfer form one trophic level to the next?
   a. 5% b. 10% c. 15% d. 20%

4. Compare and contrast pyramids of energy and pyramids of biomass. Include at least two similarities and two differences.

5. Explain the water cycle describing at least four of the processes involved in the cycle.

6. Identify and describe two different roles bacteria perform in the nitrogen cycle.

7. What is another way in which human activity is increasing the amount of atmospheric CO_2 besides the combustion of fossil fuels, and what are the potential global effects of these changes in CO_2 levels?

8. One of the important tasks of the nitrogen cycle is to change atmospheric nitrogen (N_2) to the form that plants can use. What is the usable form of nitrogen for plants?
   a. Ammonia b. Nitrites c. Nitrates d. Amino

9. Why must nutrients such as carbon, nitrogen, and water be constantly recycled?
   a. Life would not be properly sustained without them being recycled.
   b. Nutrients would be locked in dead bodies and wastes and would not be available to organism.
   c. Since these cycles are "closed systems," no more nutrients will be added to them.
   d. All of these are why nutrients are constantly recycled.

10. Contrast the movement of energy and the movement of matter (nutrients) in an ecosystem.

APPENDIX J

POST TREATMENT QUESTIONNAIRE

Directions: The statements in this survey have to do with your opinions and thoughts about science teaching and learning in school and the importance of science in your life. Please read each statement carefully, and circle the number that best expresses your own thoughts. This questionnaire is completely voluntary and will in no way affect your grade or class standing.

Post-Treatment Questionnaire

1. The class activities helped me improve my oral communication skills by exchanging information through speaking and listening.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

2. The class activities helped me improve my written communication skills by passing information and understanding to the class through written materials.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

3. The interaction with others during class activities helped me improve my teamwork by working towards a common goal.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

4. The class activities helped me improve my critical thinking skills by analyzing information to form an argument or reach a conclusion supported by evidence.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

5. The class activities helped me improve my planning, organizing, and coordinating efforts to accomplish a goal.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

6. The class activities helped me process information through evaluating and interpreting information presented in models, diagrams, and text.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

7. The class activities help me reflect on my own learning and participation in the group in order to be successful.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

8. The class activities helped me become more confident in learning and understanding biology.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

9. The class activities helped me think about by own thinking, how I learn and being more aware of my own knowledge.

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

10. The class activities prepared me to do better on biology assessments (quizzes & tests).

1 Strongly Agree 2 Agree 3 Neutral 4 Disagree 5 Strongly Disagree

APPENDIX K

POST TREATMENT INTERVIEW QUESTIONS

Answering these interview questions is completely voluntary and will in no way affect your grade or class standing.

Post Treatment Interview Questions

1. Did the POGIL teaching strategy help you think differently about the biology content compared to the teacher lecturing about the material? If so, how?

2. Do you think the POGIL teaching strategy helped you develop skills that would be useful in other classes or in other situations outside of class? If so, how? What skills do you think improved?

3. Do you think you were more engaged in class when you were learning biology through POGIL? How did this compare to learning through lecture?

4. Did learning biology through POGIL affect your attitude towards learning biology? How did this compare towards learning biology through lecture?

5. If you were to change anything about learning through POGIL, what would you change and why?

6. How would you summarize your experience learning biology using POGIL?

7. Is there anything else you would like me to know?