DISCIPLINE-BASED EDUCATION RESEARCH: INQUIRY-BASED LEARNING TROUGH A PARTIALLY-FLIPPED CLASSROOM

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ABSTRACT

DISCIPLINE-BASED EDUCATION RESEARCH: INQUIRY-BASED LEARNING TROUGH A PARTIALLY- FLIPPED CLASSROOM

by Bethany Gettings

The Next Generation Science Standards (NGSS) expect teachers to teach through inquiry-based instruction, helping students develop a deeper understanding of science through more hands-on learning. However, many teachers did not experience inquiry-based science courses in their teacher preparation programs. To better prepare K-8 science teachers, we revised an undergraduate introductory biology course to incorporate aspects of the three-dimensional learning as expected by the NGSS. This project reports on the outcomes of the lecture redesign, which utilized a “partially-flipped” approach that integrated the “disciplinary core ideas” and “scientific practices” dimensions of the NGSS. Differences in content learning outcomes, understanding of inquiry-based instruction, and attitudes toward science are explored between the partially-flipped (n=82) vs. non-flipped (n=64) design; and insight is offered into whether the use of flipped instructional designs to gain more class time for in-class group activities is an effective trade-off. Our results provide evidence in support of the use of a partially-flipped approach on developing a deeper understanding of content matter, demonstrated here through increased exam essay scores, and reflections of positive attitudes towards inquiry-based pedagogical methods.

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INTRODUCTION

In the United States (US), student academic achievement in science continually ranks average or below on international assessments (Desilver, 2017). One of these assessments is the Program for International Student Assessment, or PISA. The PISA is a highly regarded cross-national academic exam designed and coordinated by the Organization for Economic Cooperation and Development (OECD) to assess the way school systems in different countries are preparing their youth to be educated adults in society (OECD, 2016c). Approximately 540,000 15-year-old students in over 72 global economies were assessed in the PISA 2015 (OECD, 2016b). Scholastic performance was assessed in science, math, and reading, with science literacy as the core subject area (OECD, 2016b). Since 2006, when science literacy was last the major domain of the PISA, the US has had no significant change in performance (OECD, 2016a) and currently ranks 19th in science performance among participating nations (OECD, 2016b).

The perceived consequences of static and comparatively low results on international exams such as the PISA have attracted the attention of politicians, educators, and scientists (Funk & Rainie, 2015). According to the OECD (2016a), the dire state of science education has gained recognition, and support for a much-needed educational reform in the US is increasing. *PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematic and Financial Literacy* (OECD, 2016c) provides three foundational principles of science learning upon which instruction to improve scientific literacy can be built upon: 1) active science instruction; 2) engaging and building upon students' prior knowledge, interests and backgrounds; and 3) reflecting the nature of science.

The most recent effort to raise science standards in the US has been initiated via the Next Generation Science Standards (NGSS, 2013). The framework for the standards was developed by the National Research Council (NRC) (2011), and consists of three dimensions: Scientific Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The three-dimensional learning presented within the framework calls for a pedagogical approach in which students learn scientific content while engaging in scientific practices and applying cross-cutting concepts (NRC, 2011). Evidence from education research suggests that this approach will allow students to develop a deeper understanding of science through more hands-on learning (NRC, 2011).

While the NGSS framework provides the strongest recommendation of this approach thus far (Park-Rogers & Abell, 2008), efforts to promote this type of "inquiry-based" science teaching have been ongoing for decades (e.g. The Learning Cycle (Karplus & Their, 1967; and the Biological Science Improvement Study (BCBS) 5E instructional model (Bybee & Landes, 1990)). Despite these efforts, the teaching of science in K-12 classrooms has not experienced the type of transformation that these recommendations call for (OECD, 2016a). One of the most important factors determining the quality of science education for students is the quality of their science teacher (Wang *et al*., 2011). An impediment to attempts to implement inquiry, especially at the K-8 level, is that few elementary science teachers have experienced inquiry as science students. Because most of our current in-service teachers have come through the traditional transmission method of science instruction in our colleges and universities, when the standards push them to start teaching through inquiry, they have no personal frame or reference to base their changed instruction on. Studies have suggested that teachers often model their own instruction on the ways they were taught (Wainwright *et al.*, 2004). These teachers graduating from our universities then go on to teach their K-12 courses by mostly direct instruction. The children leaning those K-12 districts go on to college, expecting and prepared only to be taught the same way. Some of them go on to become teachers themselves. This is a cycle that needs to be broken. The previous National Science Education Standards (NSES), published in 1996, made this same case, stating, “The vision of science and how it is learned as described in the Standards will be nearly impossible to convey to students in schools if the teachers themselves have never experienced it” (NRC, 1996).

Sixteen years later, these same types of statements are being made in the new reports on teacher preparation (OECD, 2016a), but little has changed. A critical piece in preparing teachers to meet the increased pedagogical and content demands within raised science standards, such as NGSS, has been missing. That missing piece is the alignment of undergraduate science experiences with the types of inquiry-based experiences future teachers will be expected to provide in their classrooms. It is during science teacher preparation programs that we can help future teachers develop the knowledge and skills necessary to become effective science teachers.

This set of knowledge and skills includes both the science content and practices defined by the NGSS and the teaching techniques required to effectively teach science to students. This intersection of content knowledge and pedagogical knowledge is defined as Pedagogical Content Knowledge (PCK) (Shulman, 1986). PCK includes discipline-specific knowledge such as what examples and analogies are most relevant for specific concepts, what common misconceptions students might have related to the content, and what teaching strategies are most effective in leading students to a deeper understanding of the discipline (Magnusson *et al.*, 1999).

To provide learning experiences for preservice K-8 science teachers to develop pedagogical content knowledge, we revised an introductory biology course to align more closely with the three dimensions of NGSS, while also incorporating an introduction to pedagogy. This innovative introductory biology course was designed with the needs of preservice teachers at its foundation and aims to provide rich data that can inform change in science courses across the nation. The design of the course included revision of the labs to focus on NGSS scientific practices in an inquiry-based format, an additional weekly laboratory session focused on a discussion of pedagogy in the context of the biology content being covered each week, and revision of the lecture portion to provide more opportunities for student-centered active learning. For purposes of this research, we define "active learning" as the use of in-class cooperative group activities that require students to apply scientific practices (e.g., using models, interpreting data, supporting claims with evidence). Specific revisions to the course were implemented in a step-wise manner to allow assessment of the effectiveness and relative impact of different parts of the design. Here, we report on the outcomes of the lecture redesign, which utilized a "partially-flipped" approach (described below) to provide more time in-class for collaborative team activities.

In more traditional teaching practices, the implementation of collaborative learning exercises is hindered due to the perceived lack of time (Barak & Shakhman, 2008). The flipped classroom is an inventive pedagogical approach that switches, or flips, work that is traditionally done in class with work that is done for homework (Gilboy *et al.*, 2015). In utilizing the flipped classroom approach, class time is freed up due to removing majority, or all, of the direct instruction to out-of-class learning activities, allowing for more active and engaging in-class activities and instruction (Day and Foley, 2006). Common examples of out-of-class learning activities utilized by flipped-classroom instructors include watching a pre-recorded lecture or interactive video, listening to a podcast, or reading an assigned article or textbook chapter (Bergmann and Sams, 2012; Johnson *et al.*, 2015). Undergraduate courses that have adopted the flipped classroom attempting to develop a deeper comprehension of content matter have shown positive results (Gross *et al.*, 2015; Hamdan *et al.*, 2013; O'Flaherty *et al.*, 2015).

Despite these advantages, instructors may be reluctant to adopt a flipped model for a variety of reasons. In a fully-flipped classroom model, students are required to be responsible, independent learners as they are required to learn significant amounts of content on their own outside of class, and are then expected to apply it effectively to in-class assessments. Additional challenges with this pedagogical style arise in the increased work-load for the instructor to develop out-of-class and in-class learning activities that appeal to multiple learning strategies, as well as not being able to provide immediate feedback to questions regarding content covered in the assigned out-of-class material (Bergmann and Samms, 2012). To address these challenges, our "partially-flipped" model embraces a more blended approach; incorporating some of the efficient and familiar traditional lecture aspects (Prober & Heath, 2012) with the interactive and engaging components of a flipped classroom (Gilboy *et al.*, 2015).

The focus of this research is to help determine whether the use of a partially-flipped instructional design to gain more time for in-class group activities is an effective trade-off by examining content and pedagogical knowledge differences between a partially-flipped vs. non-flipped class. We hypothesized that the use of a partially-flipped instructional design in an introductory biology course for preservice teachers would better prepare K-8 Science teachers for inquiry-based teaching. With the additional in-class time provided in the partially-flipped model allowing for an investigation-centered experience, predictions from this study were that students would become more effective "Next Generation" science teachers through:

1. developing a deeper understanding of scientific content (content knowledge);
2. gaining a better understanding of inquiry-based instruction (pedagogical knowledge); and
3. having a more positive attitude toward science (course attitude).

CHAPTER II

METHODS

Course Design

The course in which this research was implemented is the life science course taken by all preservice K-8 teachers at a large, Midwestern doctoral university. Most of these students take the course in their first year of college. Preservice elementary teachers also take four credits of physical science and four credits of earth science.

This course is designed differently from both major and non-major introductory biology courses, in that it involves a method of training science teachers by integrating science content with pedagogy practices to better prepare teachers to meet the increasing demands in science education. Course standards are based on the NGSS (NGSS, 2013) and include all three dimensions of the standards: scientific practices, disciplinary core ideas, and cross-cutting concepts. The three dimensions of the standards are outlined in Table 1. In addition, students gain experience with pedagogical concepts and practices (e.g. writing learning objectives, assessment design, and the learning cycle) during lab. The key design feature of the course is that the preservice teachers are learning science in the same type of student-centered and inquiry-based approach that the NGSS call for them to use in their own teaching of science.

Table 1: Dimensions of the Next Generation Science Standards (NRC, 2011).

Dimension 1: Scientific and Engineering Practices 1. Asking questions (for science) and defining problems (for engineering) 2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Constructing explanations (for science) and designing solutions (for engineering) 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information.
Dimension 2: Crosscutting concepts that have common application across fields 1. Patterns 2. Cause and effect: Mechanism and explanation 3. Scale, proportion, and quantity 4. Systems and system models 5. Energy and matter: Flows, cycles, and conservation 6. Structure and function 7. Stability and change
Dimension 3: Core ideas in Four Disciplinary Areas *Physical Science* PS 1: Matter and its interactions PS 2: Motion and stability: Forces and interactions PS 3: Energy PS 4: Waves and their applications in technologies for information transfer *Life Science* LS 1: From molecules to organisms: Structures and process LS 2: Ecosystems: Interactions, energy, and the dynamics LS 3: Heredity: Inheritance and variation of traits LS 4: Biological Evolution: Unity and diversity *Earth and Space Sciences* ES 1: Earth's place in the universe ES 2: Earth's systems ES 3: Earth and human activity *Engineering, Technology, and the Application of Science* ETS 1: Engineering design ETS 2: Links among engineering, technology, science, and society

This research was implemented over two semesters, Spring 2016 and Fall 2016, in two lecture sections of the course, which met three times a week for fifty minutes. The course also includes a weekly 3-hour lab, which was kept consistent during both semesters. The lecture portion of Spring 2016 (*n*= 64) semester was carried out in our partially-flipped classroom design (experimental group), whereas Fall 2016 (*n*= 82) lecture was not flipped (control group). The same instructor taught both the experimental and control lecture sections, and students were randomly assigned to formal cooperative groups ranging in size from 4-6 students for completion of the in-class learning activities.

Elementary education majors at the university attract higher proportions of females (31:1 female to male ratio) (Office of Institutional Research, 2017), and the same is true of this course. Ninety-one percent of the partially-flipped class was female (58 females out of the 64 students total), and 95% of the non-flipped class was female (78 females out of the 82 students total). In respect to gender demographics, our two classes were equivalent (p=0.28, z=-1.07). Differences in incoming achievement levels between the two classes were assessed by comparing high-school grade point averages (GPA), attained from the registrar. Average incoming high school GPAs for students in both classes were nearly the same (partially-flipped at 3.54±0.32; and non-flipped at 3.52±0.38), and no significant difference was found (independent two-samples t-test, p=0.70).

Partially-Flipped Classroom Design

In the partially-flipped instructional design, students were assigned outside-of-class guided readings that covered approximately 40% of the course objectives. The remaining 60% of the objectives were covered in class using mini-lectures and active learning exercises, which also incorporated some of the flipped content (approximately 10% of the course objectives covered in the out-of-class guided reading were revisited in class). The objectives were distributed based on cognitive level, with lower Bloom's level objectives (Bloom, 2001) being more often flipped and higher-level objectives preferentially selected for in-class coverage.

Non-Flipped Classroom Design

For the non-flipped classroom design, all course objectives were covered in class via lecture. Because of the additional time required to cover these previously flipped objectives, fewer active-learning exercises were possible. The in-class activities that were removed from the non-flipped design were assigned as homework to ensure that all students experienced the same full set of materials, with the only difference being which course components were completed in class with the support of peer teams and the instructor and which components were completed independently by the students outside of class. Out-of-class time spent on the homework in the non-flipped section was intended to be approximately the same as the out-of-class time spent on the flipped material in the partially-flipped section. Aside from differential use of class time, the two lecture sections, including course content and assessments, were kept consistent. See Table 2 for a detailed graphic of differences between the non-flipped and partially-flipped course designs.

Table 2: Differences in application of learning materials (indicated with gray boxes) between the non-flipped and partially-flipped course designs.

	Non-Flipped	**Partially-Flipped**
Learning Objectives		
1	Covered in Class	Pre-Class Guided Reading
2	Covered in Class	Pre-Class Guided Reading
3	Covered in Class	Covered in Class
4	Covered in Class	Covered in Class
5	Covered in Class	Covered in Class
Application Activities		
A	Cooperative Groups in Class	Cooperative Groups in Class
B	Homework	Cooperative Groups in Class
C	Homework	Cooperative Groups in Class
Quiz Questions		
Q1	Beginning of Next Class	Beginning of **This** Class
Q2	Beginning of Next Class	Beginning of **This** Class
Q3	Beginning of Next Class	Beginning of Next Class
Q4	Beginning of Next Class	Beginning of Next Class
Q5	Beginning of Next Class	Beginning of Next Class

Research methods were pre-approved by the Central Michigan University Internal Review Board and all researchers completed the Collaborative Institutional Training Initiative (CITI) training.

Data Collection and Analysis

In total, one hundred and forty-five students who signed consent forms in agreement to participate in our study and completed all summative assessments were included in the analyses. Assessments were de-identified and assigned a random number to avoid recognition of a student's name and potential researcher bias during the analysis process.

Content Knowledge

Students enrolled in both semesters were formatively assessed on their comprehension of learning outcomes through in-class quizzes held at the start of each non-exam day. The quizzes were multiple-choice format, administered using iClicker software and answered individually via students' personal iClickers. In the flipped class, 2-3 quiz questions evaluated student understanding of course objectives covered in the out-of-class guided reading and 2-3 questions reviewed content from the previous class meeting. In the non-flipped class, all five quiz questions evaluated student understanding of only the previous lecture material. The same quiz questions were asked in both sections, but were aligned with the order that students were exposed to the objectives; therefore, questions varied in timing based on the treatments (see Table 2). Overall percent correct on clicker quizzes for the partially- and non-flipped students was analyzed utilizing an independent two-samples *t*-test.

Understanding of content matter was most rigorously assessed through extended response exam essay questions. Fourteen essay questions were chosen for the analysis. These questions were aligned only with the activities the non-flipped students completed for homework and partially-flipped students completed in class as active learning exercises. The essay questions were coded following an *a priori* approach, as described by Weber (1990). Rubrics developed by the research team assessed correct concepts stated in student responses: A score of "1" indicated a correctly stated concept, whereas a score of "0" indicated the concept was either missing or incorrect. Two researchers independently scored the assessments followed by a side-by-side analysis to determine any discrepancies, at which point a third researcher reviewed the assessment and made the final decision. The total number of correct concepts over all essays was calculated per student, and a difference in performance between students in the partially- and non-flipped class was analyzed via a Mann-Whitney *U* test.

Exam questions presented as multiple choice were divided into higher and lower order thinking skills in accordance with the revised Bloom's taxonomy (Bloom, 2001). Two researchers independently ranked the questions reached a consensus on any disparities. Questions that reflected the "Remember", "Understand", or "Apply" level were identified as low cognitive level; those that reflected "Analyze", "Evaluate", or "Create" were identified as high cognitive level. The total number correct of high- and low-order questions was examined through separate Mann-Whitney *U* tests to see if the cognitive level of course objectives played a role in differences in student success on corresponding questions.

Students also completed a key-concepts pretest (provided in the Supplementary Materials) during their first lab meeting that was aligned with course curriculum and departmental learning outcomes. This key-concepts test was also re-administered as part of the final exam. Results of the key-concepts pretest were not shared with students, nor were they aware that it would be included on the final exam. Analysis on the change scores (number correct on the posttest – number correct on the pretest) was conducted via a Mann-Whitney *U* test, which allowed researchers to assess whether students in the partially- or non-flipped classrooms exhibited a difference in learning gains over the course of the class.

Pedagogical Knowledge

To assess student pedagogical knowledge and measure changes in course attitudes, analysis was conducted on a pre- and post-survey in which students self-assessed their understanding of instructional designs and beliefs toward aspects of the course (provided in the Supplementary Materials). This assessment was given to students at the first and last lab meeting. Researchers on this project collaboratively designed the assessments, which were composed of extended response questions and a Likert scale survey. No incentive was provided for students to complete the survey, which may have helped control for moderator acceptance bias, but potentially decreased student effort in self-assessing and providing answers. Furthermore, a struggle with implementing self-reporting data, one that we are not exempt to here, is the potential difference in students reflecting on current or past class experiences.

Students' pedagogical knowledge regarding inquiry-based instructional designs was qualitatively analyzed via text analysis of extended response Question 1 on the post-survey: "What are the key features that define an inquiry-based lesson?". Researchers identified the use of key words they determined central to the definition of inquiry-based teaching (e.g., students, ask, questions, active). An independent two-samples *t*-test on average key-word counts looked for differences in understanding of key features of inquiry-based lessons.

Course Attitude

Student attitudes regarding aspects of inquiry-based instruction (e.g., active learning and group work), the flipped design, and self-efficacy beliefs were measured through the Likert-scale survey. Students were queried to rank their level of agreement or disagreement to course-related statements on a scale of “strongly disagree” (scored as a 1) to “strongly agree” (scored as a 5). Quantitative analysis on the change in survey responses (post-survey response – pre-survey response) via a Mann-Whitney *U* test evaluated attitudinal differences related to the partially-flipped vs. non-flipped design.

CHAPTER III

RESULTS

Content Knowledge

There were statistically significant differences between the partially-flipped and non-flipped groups on exam essay scores and in-class clicker quizzes. Students in the partially-flipped class performed significantly better on exam essays than students in the non-flipped class (p=0.02, r=0.19). Average coding scores for the partially-flipped (76.87±18.43) and non-flipped (70.20±18.42) class are seen in Figure1. Students in the non-flipped class performed significantly better (p<0.001, *Cohens' d*=0.87) than students in the partially-flipped class on the in-class clicker quizzes. Average overall clicker quiz scores for the non-flipped (89.54± 3.20) and partially-flipped (85.58± 5.62) class are seen in Figure 2.

Students in the partially- and non-flipped classes were found to have equal performance on high- and low-level multiple choice questions and on the change scores from the pre- to post-key-concepts test. Average correct high-level multiple-choice exam questions for the partially-flipped (72.44±14.29) and non-flipped (71.53±15.39) students are displayed in Figure 3, for which results of the Mann-Whitney *U* indicated no significant difference (p=0.90). Average correct low-level multiple choice exam questions for the partially-flipped (85.38±19.17) and non-flipped (82.17±20.37) are shown in Figure 4, for which results of the Mann-Whitney *U* also indicated no significant difference (p=0.53). To conclude results of content knowledge analysis, no significant difference (p=0.40) was found in the change scores on the key concepts test between the two classes. Figure 5 depicts the average number of correct concepts on the pre- and post-key-concepts test for the partially-flipped and non-flipped classrooms, and near parallel gains are observed.

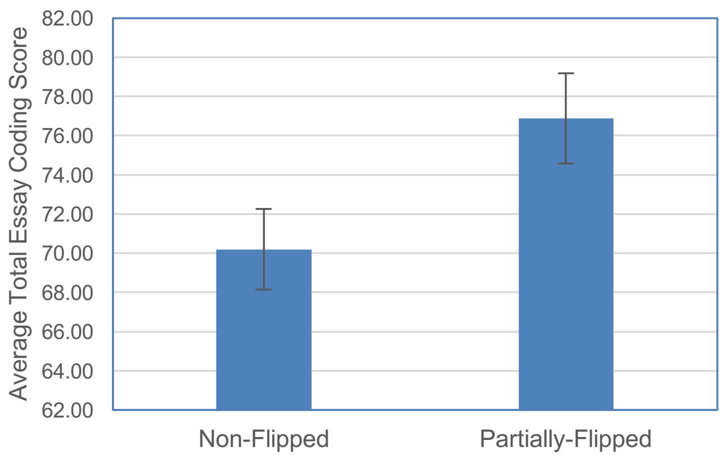

Figure 1: Average total coding scores for the partially-flipped (n=64) and non-flipped (n=81) classes. A significant difference (p=0.02, r=0.19) was found in the Mann-Whitney U test.

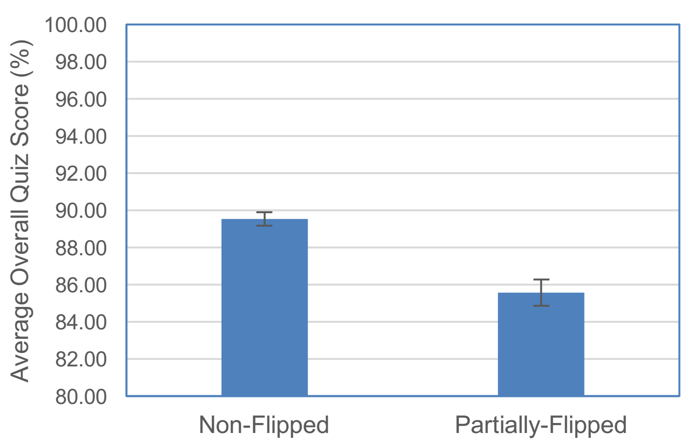

Figure 2: Average overall clicker quiz scores for the partially-flipped (n=64) and non-flipped (n=81) classes. Means were found significantly different (p<0.001, *Cohens' d* =0.87) in the independent two samples t-test.

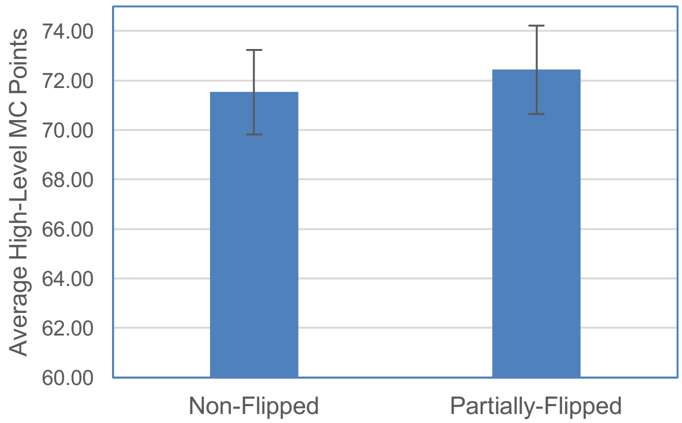

Figure 3: Average total number of correct high-level multiple-choice exam questions for the partially-flipped (n=64) and non-flipped (n=81) classes. No significant difference (*p*=0.90) was found in the Mann-Whitney *U* test.

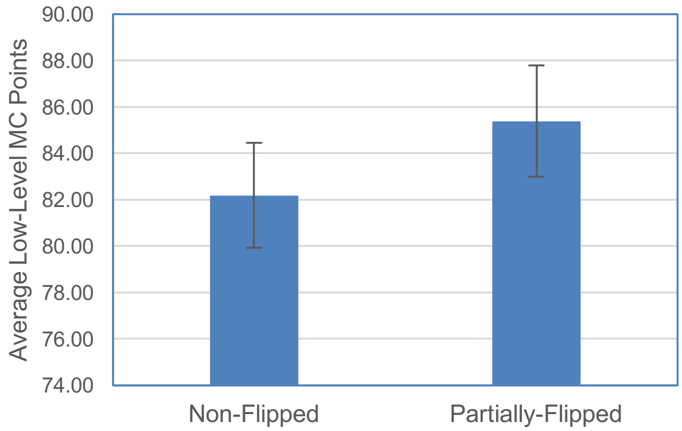

Figure 4: Average total number of correct low-level multiple-choice exam questions for the partially-flipped (n=64) and non-flipped (n=81) classes. No significant difference (*p*=0.53) was found in the Mann-Whitney *U* test.

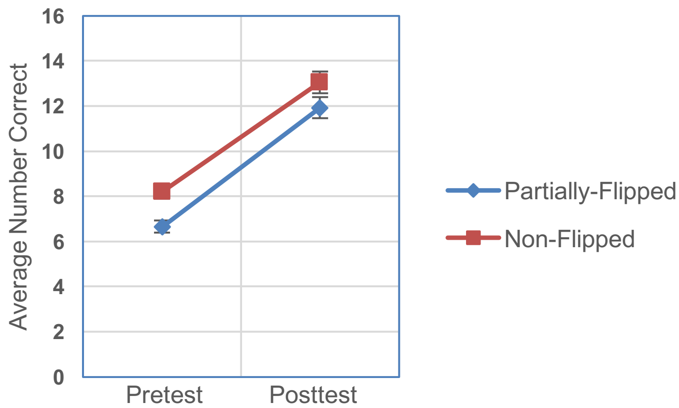

Figure 5**:** Average number correct on the pre- and posttests in the partially- flipped (n=64) and non-flipped (n=81) classes. Average change scores were found not significant (*p*=0.40) with the Mann-Whitney *U* test.

Pedagogical Knowledge

An independent two-samples *t*-test indicated no significant difference (*p*= 0.23, *Cohens' d*=0.10) between the partially- and non-flipped classes in students' average use of key words in identifying features of an inquiry-based lesson (extended response Question 1 on post survey). Figures 6 and 7 (produced in wordle.net) represent the relative frequencies of each of the words included in the analysis.

Figure 6: Word cloud generated to show relative frequencies of key terms used by partially-flipped students regarding key features of an inquiry-based lesson.

Figure 7: Word cloud generated to show relative frequencies of key terms used by non-flipped students regarding key features of an inquiry-based lesson.

Course Attitude

Results of the Mann-Whitney *U* tests on the change in pre- to post-survey questions are presented in Table 3. Of the twelve questions, two were found to be significant. Statement 6: "I prefer (or feel positive about) my science courses using cooperative group work" was found to be significant at p=0.01 (r=0.20); and Statement 8: "I prefer (or feel positive about) my science courses to primarily using lecture approach" was found to be significant at p=0.02 (r=0.22). Figures 8 and 9 graphically represent the average response from the partially- and non-flipped students on these two questions. No significant differences were found between the partially- and non-flipped classes regarding changes in student attitude toward science (Statements 9-12).

As seen in Figure 8, students in both treatments had an increase in their attitude toward in-class cooperative group work. A more positive increase toward this inquiry-based element was felt by students in the non-flipped classroom. Non-flipped students had a more positive opinion of the lecture approach at the end of the semester; whereas, partially-flipped students indicated a negative feeling toward their science courses using primarily the lecture approach (see Figure 9).

Table 3: Pre- and Post-survey questions, change scores for the partially-flipped (PF) and non-flipped (NF), and resulting Mann-Whitney *U* *p*-values.

Statement	**PF Change Score**	**NF Change Score**	***p*-value**
1. The flipped classroom approach is an effective teaching strategy.	0.3	0.3	0.50
2. I prefer (or feel positive about) my science courses using the flipped approach.	0.1	0.1	0.74
3. The active learning approach is an effective teaching strategy.	0.3	0.3	0.40
4. I prefer (or feel positive about) my science courses using the active learning approach.	0.2	0.3	0.14
5. Working in cooperative groups is an effective teaching strategy.	0.1	0.3	0.07
6. I prefer (or feel positive about) my science courses using cooperative group work.	0.1	0.4	0.01
7. Lecture is an effective teaching strategy.	-0.1	0.2	0.38
8. I prefer (or feel positive about) my science courses to primarily using lecture approach.	-0.3	0.2	0.02
9. I am good at science.	0	0.1	0.38
10. I enjoy science classes.	-0.2	-0.2	0.62
11. I often read science articles or texts.	-0.2	-0.1	0.70
12. I usually am able to understand what I read in science articles or texts.	-.1	0	0.21

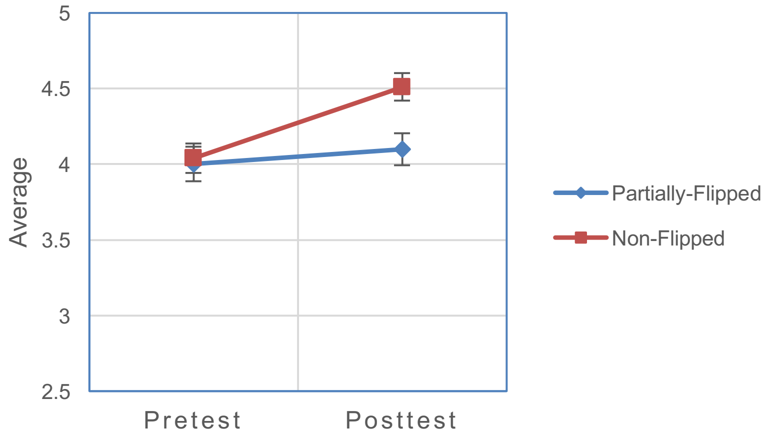

Figure 8: Average response to the pre- and post-survey question, “I prefer (or feel positive about) my science courses using cooperative group work.” A significant difference (p=0.01, r=0.20) was found in the Mann-Whitney U test on change scores between the partially flipped (n=64) and non-flipped (n=81) classes.

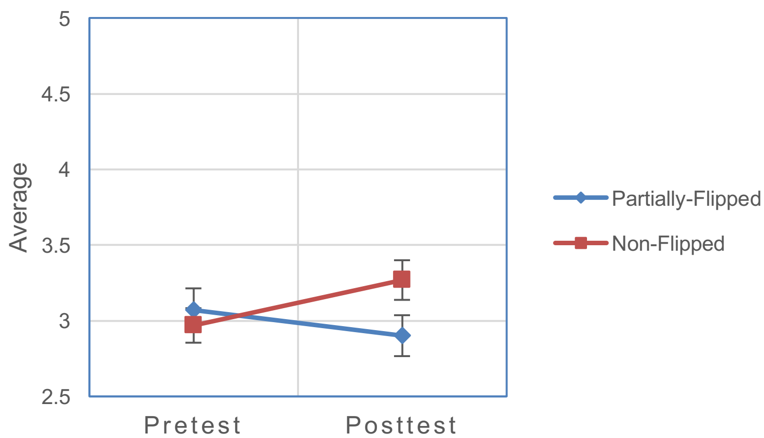

Figure 9: Average response to the pre- and post-survey question, “I prefer (or feel positive about) my science courses to primarily using lecture approach.” A significant difference (p=0.02, r=0.22) was found in the Mann-Whitney U test on change scores between the partially flipped (n=64) and non-flipped (n=81) classes.

CHAPTER IV

DISCUSSION

The findings of this project aim to narrow the gap between the biology experience that K-8 teachers are expected to provide their students according to the NGSS and how preservice teachers experience biology courses at the university level. In the present study, the call for learning through inquiry-based instruction (NRC, 1996) is examined through a partially-flipped introductory biology class designed specifically for preservice teachers. The evidence provided here supports the use of a partially-flipped instructional design to gain more class time for in-class, inquiry-based group activities.

Our first key objective was to assess whether differences in assessments of content knowledge, as measured by exam essays, in-class clicker quizzes, and a key-concepts pre- and posttest, existed between the partially- and non-flipped classes. In contrast to the studies by Whillier (2015) and Yong et al. (2015), which showed no learning gains attributable to the flipped technique, students in our partially-flipped class attained better academic results on exam essay questions. These gains are consistent with noted learning gains of students in flipped-classroom research by Gilboy et al. (2015), Lax, Morris, and Kolber (2016), and Roach (2014).

Students in flipped classroom settings have been found to be more efficiently engaged in activities aligned with higher levels of Bloom's taxonomy (Gilboy *et al.*, 2015; Gaughan, 2014; and Gross *et al.*, 2015). Peer discussion, more strongly emphasized in the partially-flipped design, has also been found to increase student learning (Linton *et al.*, 2014). We took into consideration the content of student feedback and believe students' increased engagement and cooperative group work on the higher-order in-class activities in our partially-flipped class was a factor in increased performance on the higher-order exam essays. Student feedback from the extended-response post-assessment question, "Did you like the design/layout of the classroom? Please provide any specific examples of how it helped or hindered your learning experience." indicated:

> "Sitting in groups was helpful in encouraging a collaborative environment."
> "Working with my group helped me see other ideas that I didn't think about."
> "The fact that it was so interactive made a big difference."
> "The small groups allowed for good time management during activities, and allowed everyone to get involved."
> "I liked that instead of notes, reading, and lecture, the teacher involves the students and prepares activities or group work/discussion."

A significant difference on overall in-class clicker quiz performance was found between our two groups of students, with non-flipped students showing better performance on these formative assessments. These results may be influenced by where and how the evaluated content was covered, with students in the non-flipped class only being quizzed on content that had previously been covered in class while students in the partially-flipped class received some of those same quiz questions over content they were responsible for outside of class. It is possible that students in the partially-flipped class had more difficulty learning this content on their own or that there was a lack of student responsibility for independent learning and that some portion of the students did not adequately prepare for class on any given day. The non-significant differences between both low-level and high-level multiple-choice exam questions, which were similar in both content and Bloom's level to the quiz questions, indicates that any disparity in understanding of these concepts was eliminated by the time of the summative assessment and suggests that the lack of daily preparation was the more likely cause.

Non-significant difference regarding students' gain in understanding of core curriculum and departmental outcomes (from the key-concepts test) was found, along with previously-noted equal performance on high-level and low-level multiple choice questions. Performance on lower-level objective assessments, such as the key concepts test and low-level multiple choice questions, agree with previous research (Dolmans *et al.*, 2015; Linton *et al.*, 2014) that cooperative group activities improve student learning preferentially on higher cognitive level objectives and may not be important for lower objectives. The most rigorous measure of learning we assessed was from student performance on exam essays, which challenged students to create a response rather than select a response. It was on these assessments that our analysis did find a significant difference, suggesting that the effects of the partially-flipped approach may be stronger for higher-level thinking situations.

The second key component of this research was to assess whether the increased in-class exposure to inquiry-based and student-centered instruction in our partially-flipped model instilled a better understanding of inquiry-based instruction within these students. Evaluation on key features of an inquiry-based lesson identified by students found no significant difference between the two classes. These findings suggest students in both classes held a level understanding of inquiry-based instructional design features at the end of their course experience. Likely, these results are due to the inquiry-based lab component both sections were exposed to, and providing in-class opportunities, albeit limited amounts in the non-flipped course, to experience science through inquiry-based methods (e.g., cooperative group-work).

Thirdly, this project examined students' self-reflection regarding attitudes toward science. Equal attitude shifts, or no shift at all, from the beginning to completion of the class were reported on most of the assessed aspects, however, significant differences were found regarding two instructional strategies: preference for the use of in-class cooperative group work, and the primary use of the lecture approach in science courses.

Results from the analysis of Likert survey Statement 6 show that students in both treatments had a positive increase in their perception of in-class cooperative group work. Meta-analyses of cooperative learning research (Johnson, Johnson, & Smith, 2006; Johnson, Johnson, & Stanne, 2000; Kyndt *et al.*, 2013; Slavin, 1991) offer support of the improved attitude results. To extend on this, the work of Frederick (1987), and Persky and Pollack (2010) found that cooperative-learning strategies can be particularly beneficial in large classes, such as those common at the introductory level, as a way for instructors to engage more students in class discussion and better monitor student understanding. In combination with past research, we offer our findings as support of cooperative group work as an effective teaching strategy. Qualitative data provided by students in both classes reinforce these claims with a sense of engagement from the partially-flipped students as noted above, and from statements provided by students in the non-flipped classroom:

> "Working in groups helped me when I had questions."
> "Even though in lecture we mostly work individually, we also got to work together which helped if something was ever confusing or challenging."
> "We were able to work in small groups while also receiving lectures, there was a good combination."

Analysis of Statement 8, regarding student perception on preferring a lecture approach in their science courses was interpreted with caution, for it is possible that students misinterpreted the “lecture approach” terminology. Students’ idea of the “lecture approach” was not further probed in post-survey extended response questions, but we do consider that students in the partially-flipped class interpreted the lecture question as referring to a more traditional lecture setting with no in-class, cooperative group-work; whereas, students in the non-flipped class interpreted the lecture question as referring to their lecture experience, which included a small amount of cooperative group work.

Conclusion

To train preservice science teachers to meet the raised content and pedagogical components of newly established K-8 science standards, undergraduate science should be designed to provide learning experiences that align closely with experiences they will be expected to provide in their classrooms. We believe that the use a partially-flipped classroom model, to provide a more inquiry-based in-class component, is an effective way to provide this type of experience through our findings of deeper understanding of content matter, demonstrated here through increased exam essay scores, and expression of positive feelings towards inquiry-based pedagogical methods.

Further research into the effects of a partially-flipped classroom model on development of pedagogical content knowledge is recommended. Replication studies examining learning outcomes over multiple semesters combined with a more heterogeneous group with respect to gender is suggested, and could lead to different results than those reported here. Even with the present limitations, the key strength of this research is that all variables, including content and sequence of delivery, pedagogical activities, and instructor were kept consistent. Only the use of in-class time varied.

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CENTRAL MICHIGAN UNIVERSITY

BIO 165 PRE TEST **NAME:**

1. What are the key features that define an inquiry-based lesson?

2. What does inquiry look like in practice?

3. Have you heard of the term “flipped classroom” before? If yes, please describe your understanding of what it means.

4. Have you heard of the term “active learning classroom” before? If yes, please describe your understanding of what it means.

5. Have you had experience working in cooperative groups in previous classes? Was your experience positive? Please explain.

6. What percentage (0-100%) of the course material do you think is appropriate for students to be expected to learn on their own outside of class? ________

7. How many hours outside of the classroom (studying, reading, etc.) per week do you expect to spend on this class? ________

8. What grade do you anticipate getting in this class? ________

9. Please read the following statements and place and "X" in the appropriate box

Statement	Strongly Agree	Agree	Not Sure, Neutral	Disagree	Strongly Disagree
The flipped classroom approach is an effective teaching strategy.					
I prefer (or feel positive about) my science courses using the flipped approach.					
The active learning approach is an effective teaching strategy.					
I prefer (or feel positive about) my science courses using the active learning approach.					
Working in cooperative groups is an effective teaching strategy.					
I prefer (or feel positive about) my science courses using cooperative group work.					
Lecture is an effective teaching strategy.					
I prefer (or feel positive about) my science courses to primarily using lecture approach.					
I am good at science.					
I enjoy science classes.					
I often read science articles or texts.					
I usually am able to understand what I read in science articles or texts.					

10. Please read the following passage and answer the questions:

Tropical deciduous forests

Tropical deciduous forests usually occur in hot lowlands outside the equatorial zone (between 10° and 30° latitude) where rainfall is more seasonal, and the dry season more pronounced and more extensive, than in regions of tropical rain forests. Compared with a tropical rain forest, the canopy of a tropical deciduous forest is lower and more open and, because more light reaches the ground, there is often more understory vegetation. To conserve water, many of the trees and understory plants shed their leaves during the long dry season, although much flowering and fruit maturation occur during this time.

The dominant vegetation is often called rain-green forest because forest trees leaf out during the first heavy rains following the dry season. The most luxuriant form is the monsoon forest, the layperson's "jungle." Monsoon forests, especially well developed in southern Asia, has many large leaves and dense undergrowth rich in bamboos. These areas are frequently drenched with torrential rainstorms, and some are among the rainiest, but most seasonal, habitats in the world. (Lomolino, 2010)

A. What is the dominant vegetation of a tropical deciduous forest called?

B. What latitudes are tropical deciduous forests found in?

C. Why is there more understory in tropical deciduous forests as opposed to tropical rain forests?

D. Would water sources, such as rivers and streams, vary or remain constant in a tropical deciduous forest? Use evidence from the reading to support your conclusion.

E. Would a carnivorous bird (diet consisting of animals) be able to hunt better in a tropical deciduous forest or a tropical rain forest? Use evidence from the reading to support your conclusion.

POST TEST NAME:

1. What are the key features that define an inquiry-based lesson?

2. What does inquiry look like in practice?

3. Describe your understanding of a flipped classroom teaching strategy?

4. Describe your understanding of an active learning teaching strategy?

5. Did you like the design/layout of the classroom? Please provide any specific examples of how it helped or hindered your learning experience.

6. What percentage (0-100%) of the course material were you expected to learn on your own outside of class? ________

7. What percentage (0-100%) of the course material do you think is appropriate for students to be expected to learn on their own outside of class? ________

8. How many hours outside of the classroom (studying, reading, etc.) per week did you spend on this class? __________

9. Describe your experience working in cooperative groups in this class. Was your experience positive? Did all group members contribute? Please explain.

Please read the following statements and place and “X” in the appropriate box

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The flipped classroom approach is an effective teaching strategy.					
I prefer (or feel positive about) my science courses using the flipped approach.					
The active learning approach is an effective teaching strategy.					
I prefer (or feel positive about) my science courses using the active learning approach.					
Working in cooperative groups is an effective teaching strategy.					
I prefer (or feel positive about) my science courses using cooperative group work.					
Lecture is an effective teaching strategy.					
I prefer (or feel positive about) my science courses to primarily using lecture approach.					
I am good at science.					
I enjoy science classes.					
I often read science articles or texts.					
I usually am able to understand what I read in science articles or texts.					
Please answer the following questions based on lecture portion of the course only.					
I could always see the professor during class.					
I could always hear the professor during class.					
The technology in the classroom was helpful and well utilized.					
I could easily participate in class discussions.					
I could easily participate in group discussions.					
Every member of my group participated equally.					
The team activities helped me understand the material.					
The tempo or pace of the class was too fast and I felt rushed during group activities.					
In comparison to other classes, I participated in full-class discussions more frequently.					
In comparison to other classes, I participated in group/team discussion more frequently.					
In comparison to other classes, I prepared for class more frequently.					
The tests in this class were extremely difficult.					
I was usually well-prepared for class.					
I enjoyed this class more than other classes.					
I (almost) always paid attention in class.					
Rate your effort outside of class in comparison to your other classes.	Much more	More	Equal	Less	Much less

Rate your level of attention in this class compared to your other classes.	Much more	More	Equal	Less	Much less
Rate the difficulty of this class in comparison to your other classes.	Much more	More	Equal	Less	Much less

Key Concepts Pretest: Choose the one alternative that best completes the statement or answers the question.

1. Science is ______.
    a. the explanation of structures and processes based on verifiable observations and measurements
    b. the search for truth
    c. an organized set of principles for how to ethically and morally behave
    d. the explanation of phenomena based on supernatural causation
    e. all of the above

2. Why is water considered a polar molecule?
    a. Both hydrogens are at one end of the molecule, and oxygen is at the other end.
    b. The oxygen is found between the two hydrogens.
    c. Its electrons spend more time with its oxygen than with either hydrogen.
    d. The negatively charged oxygen atom attracts the positively charged hydrogen atoms.

3. If one strand of a DNA double helix has the sequence AGTACTG, what will be the sequence of the other strand?
    a. GTCATGA
    b. TCATGAC
    c. CTACAGT
    d. GACGTCA
    e. AGTACTG

4. When using a light microscope to view a cell you obtained from scraping under your fingernails, you notice that the cell lacks a nucleus; therefore, you conclude that the cell must be a type of ______ cell.
    a. Prokaryotic
    b. Eukaryotic
    c. Plant
    d. Animal

5. When two solutions that differ in solute concentration are placed on either side of a selectively permeable membrane, and osmosis is allowed to take place, the water will ______.
    a. exhibit a net movement to the side with lower solute concentration
    b. exhibit an equal movement in both directions across the membrane
    c. exhibit a net movement to the side with lower water concentration
    d. exhibit a net movement to the side with higher water concentration

6. Breathing faster when we exercise is necessary to expel ______.
    a. oxygen and bring in more carbon dioxide to support aerobic metabolism
    b. carbon dioxide and bring in more oxygen to support aerobic metabolism
    c. carbon dioxide and bring in more oxygen to support anaerobic metabolism
    d. oxygen and bring in more carbon dioxide to support anaerobic metabolism

7. Photosynthesis contributes to plant growth by _____.
    a. synthesizing carbon dioxide and making cellulose
    b. taking in oxygen and making wood
    c. taking in carbon dioxide and making carbohydrates
    d. releasing the energy in cellulose to make new leaves and roots

8. The cell cycle results in the production of ______.
    a. four haploid cells, each with the same amount of genetic material but with different genetic information
    b. two diploid cells, each with the same amount of genetic material but with different genetic information
    c. four diploid cells, each with the same amount of genetic material and the same genetic information
    d. two diploid cells, each with the same amount of genetic material and the same genetic information

9. Attached earlobes are recessive to free earlobes. What genotypic ratio is expected when an individual with attached earlobes mates with an individual heterozygous for free earlobes?
    a. 3:1
    b. 9:3:3:1
    c. 1:2:1
    d. 1:1
    e. 2:1

10. If a strand of DNA has the sequence AAGCTC, transcription will result in a(n) ______.
    a. single RNA strand with the sequence UUCGAG
    b. single DNA strand with the sequence TTCGAG
    c. single RNA strand with the sequence TTCGAG
    d. DNA double helix with the sequence AAGCTC for one strand and TTCGAG for the complimentary strand

11. Why is it that cells in different body tissues have different functions?
    a. The mutations that have accumulated in the cells of different tissues control functions.
    b. The age of the cells making up the tissues plays a role.
    c. The cells contain different genes.
    d. The cells exhibit different patterns of gene expression.

12. Ethical dilemmas raised by DNA technology and knowledge of the human genome include ______.
    a. the appropriateness of creating new plants, animals, and microorganisms
    b. the potential discrimination against people predisposed to certain diseases
    c. the safety of GM foods
    d. all of the above

13. Which one of the following statements is true?
    a. Exposure to antibiotics causes bacteria to change and become resistant.
    b. Natural selection works on variation already present in a population.
    c. Sexual recombination decreases variation.
    d. Organisms evolve structures that they need.

14. Speciation requires ______.
    a. genetic isolation
    b. geographic isolation
    c. long periods of time
    d. periods of rapid evolutionary change

15. According to the theory of endosymbiosis, which organelles evolved from small prokaryotes that established residence within other, larger prokaryotes?
    a. Golgi apparatus and endoplasmic reticulum
    b. vacuoles and lysosomes
    c. mitochondria and chloroplasts
    d. centrioles and ribosomes

16. Which of the following correctly illustrates the sequence of the origin of modern groups of plants?
    a. ferns, gymnosperms, angiosperms, bryophytes
    b. ferns, gymnosperms, bryophytes, angiosperms
    c. bryophytes, ferns, gymnosperms, angiosperms
    d. bryophytes, ferns, angiosperms, gymnosperms

17. There are more species of ______ than of any other type of animal.
    a. Annelids
    b. Arthropods
    c. chordates
    d. molluscs

18. Which of these represents the correct hierarchical order from smallest to largest?
    a. cell, organism, population, community, ecosystem
    b. organism, cell, community, ecosystem, population
    c. cell, organism, ecosystem, population, community
    d. community, population, cell, organism, ecosystem

19. How does energy flow differ from chemical cycling?
    a. Energy flows from lower to higher trophic levels; chemicals cycle fro higher to lower trophic levels.
    b. Energy cannot be created or destroyed; chemical elements can be created and destroyed.
    c. Energy can both enter and leave an ecosystem; chemical elements always remain within a single ecosystem.
    d. Energy can enter but cannot leave an ecosystem; chemical elements can leave but cannot enter an ecosystem.
    e. Energy flow is unidirectional through an ecosystem; chemical elements can be recycled within an ecosystem.

20. The primary mechanism by which CO_2 contributes to global warming is by __________.
    a. decreasing the amount of O_2 in the atmosphere.
    b. increasing planetary photosynthesis, allowing for more life on Earth, which means an increase in the production of metabolic heat.
    c. allowing more infrared radiation to reach Earth's surface.
    d. increasing the amount of O_2 in the atmosphere.
    e. preventing the radiation of heat from Earth to space.

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