Successful Instructional Strategies for Online PBL

By

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A Master's Paper submitted in partial fulfillment of

the requirements for the degree of

Master of Science in Education - STEMteach

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1 September 2021

Date

University of Wisconsin-River Falls

2021

Abstract

Recent studies have been conducted on the efficacy of Project Based Learning (PBL) **(**Saavedra, 2021; Kracjik, 2020). However, there exists a gap in the professional literature for implementing PBL in an online environment. This study seeks to find successful ways to implement PBL instructional strategies in an online environment through analysis of observational data collected on a teacher-researcher's practices in a secondary biology classroom. This study utilizes action research to compile data in a research journal and then subjects that data to thematic analysis using the Costa Qualitative Data Analysis (CQDA) technique (Costa, 2019). The results of this study identified eight strategies that lead to successful implementation of PBL. The implications of this study include providing a toolkit of instructional strategies for future online PBL educators to use, giving educators a frame of reference for changes they may need to make to other aspects of their teaching practices, and identifying potential areas for future research in online PBL education.

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Introduction

The 2020-2021 academic year was shaped by an abrupt demand for educators to provide online learning services for students in a variety of classroom settings, including classrooms teaching different age and ability levels and classrooms using various pedagogical approaches. Students across the United States have been thrust into a novel setting where they must adapt to new skills, new ways of processing information, and new ways of demonstrating mastery. Fortunately, educators have a long history of developing pedagogical approaches and strategies for addressing multiple intelligences and learning modalities. The wide variety of pedagogical approaches allows teachers to select a toolkit of strategies that assist them in creating meaningful educational experiences for their students. However, with the transition to an online environment, many of the approaches educators use need to be adapted. The intersections between various pedagogical approaches and delivering content online are unpredictable and have created a demand for research into how to apply each of these unique pedagogical approaches in an online environment. This study seeks to understand using Project Based Learning (PBL) in an online teaching format.

PBL has become one of the most popular alternatives to traditional classroom settings. This framework is a useful tool because it allows students to engage with real-world problems and create products that more closely mirror the products that adults create in the workplace than traditional homework assignments. Studies suggest that PBL is a more equitable pedagogical approach than traditional teacher-centered practices (Saavedra, 2021; Kracjik, 2020). Students from less advantaged socio-economic backgrounds tend to show gains more similar to their peers from more advantaged socio-economic backgrounds in PBL classrooms than in traditional classrooms (Saavedra, 2021). Furthermore, students from all socio-economic backgrounds tend

to show more growth in PBL classrooms than in traditional classrooms, both in academics and in social-emotional learning (Kracjik, 2020). A large-scale analysis of studies on PBL and learning outcomes suggests that PBL may improve scores on standardized measures (Condliffe et al, 2017). Because research shows that PBL can strengthen a student's academic achievement and create ties between a student's education and real-world experiences it is important to understand how to apply PBL in a variety of contexts, the most pressing of which in the 2020-2021 academic school year was how to apply PBL in an online context.

Delivering PBL in an online environment poses several challenges both to the teacher and the student. Teachers will have to adjust to new ways of delivering instructional material, providing feedback and assessment, and communicating with students. Students will have to adjust to new ways of receiving instruction, communicating with teachers, with other students, collaborating with others, completing assessments, and self-directed learning. Students have less access to space and materials in an online setting. It is more difficult for students to learn from examples that teachers may present to the class. Students may find it difficult to digest large amounts of information. Students may also be exposed to new distractions outside of the physical classroom..

To help circumvent these problems, the current study seeks to address the question:

How does a teacher design and deliver online PBL instruction in a secondary science classroom?

To address the research question, two subquestions were developed:

Subquestion 1: What aspects of PBL need to be modified for online instruction in a secondary science classroom?

Subquestion 2: What differences and similarities exist between delivering PBL

curriculum in-person and online?

These subquestions were developed to help elucidate the specific factors that may hinder a

teacher's transition to online PBL and to provide teachers with an idea of adjustments they may

need to make in their teaching practices.

To answer the research question, I developed an action research plan in which I first

identified areas of special needs that existed for my students and then attempted to create

strategies that could provide solutions to those needs. I focused on addressing needs that were

created by the emergence of the new online format and the transition that my students would

have to make into this unfamiliar territory.

Through addressing these questions, I hope to help future online PBL educators by giving

them a foundation of instructional strategies that they can draw from as they design their online

PBL curricula. Future educators can select specific strategies that have been developed through

the course of this study which they deem appropriate to their needs and goals. This study will

provide educators with knowledge about some of the broad changes that might need to occur in a

classroom transitioning to an online format.

Definitions

This section serves to provide the reader with definitions of terms that are not usually

encountered outside of the specific context in which this study was conducted.

Project-Based Learning (PBL) - Project Based Learning is a teaching method in which students

gain knowledge and skills by working for an extended period of time to investigate and respond

to an authentic, engaging, and complex question, problem, or challenge (Kingston, 2017).

Online Learning - A form of distance education in which a course or program is intentionally designed in advance to be delivered fully online. Faculty use pedagogical strategies for instruction, student engagement, and assessment that are specific to learning in a virtual environment (Bates, 2019).

Literature Review

PBL is a pedagogical approach that involves students engaging with real-world problems and creating products to demonstrate mastery of material. Students design and lead an investigation of a problem or challenge relevant to their personal interest or life experiences. PBL promotes inquiry learning and problem solving skills by having students investigate real-world problems (Efstratia, 2014). Students design their own projects, including what they will research and how they will present their findings. PBL places special emphasis on the process through which students derive content knowledge, preferring for students to learn through action rather than passively receive information. Students actively practice transferable skills as they work towards completing projects. Projects require students to address a specific challenge or question. Students engaged in PBL will create a public product to demonstrate their mastery over skills and concepts. In PBL students are involved in the decision making process, with control over many important aspects of project design, often including their topic, their focus for research, the skills they will practice while developing their product, the design of their product, and how their product will be shared. PBL involves students working in collaboration and communication with other students, both to complete projects together and to evaluate each other's work. Students apply learned concepts in novel ways to test and extend their content knowledge. Eight basic elements of project design are the basis for project-based learning, as

reported by the Buck Institute for Education (Kingston, 2017). The eight elements of project

design are presented in Table 1.

Table 1

Essential Project Design Elements

Project Design Element	Description
1. Key knowledge, Understanding, and Success Skills	A project should be focused on student learning goals. It should also include standards-based content and skills. These skills include critical thinking, collaboration and self management.
2. Challenging Problem or Question	The challenge level of the problem or question should be appropriate for the student(s) working to solve it. The problem or question should also be meaningful to the student(s).
3. Sustained Inquiry	A continued process of student(s) asking questions, finding resources to answer the questions, and applying the new information.
4. Authenticity	A project should contain a connection to the real-world. If there is no real-world

	connection, there should be an impact or relation to students' own interests.
5. Student Voice and Choice	Students should have a say in what they create and how it is created.
6. Reflection	Students and teachers both reflect on the project. What was effective? What obstacles were encountered and how were they overcome?
7. Critique and Revision	Feedback is given and received by students. It is then used to improve the project process and product.
8. Public Product	Students' work becomes public through display/presentation.

PBL is a pedagogical approach that lends itself to active learning. (García-Peñalvo, F. J., Alarcón, H., & Domínguez, Á., 2019). PBL engages students in active learning, because it requires students to thoroughly examine what they know and do not know about their topic, evaluate different solutions to the problem, design and produce a product that addresses their problem, and publicly report their findings (Nilson, 2010). In PBL, instead of students passively absorbing information, they are actively interacting with knowledge and the world around them to learn how to apply content knowledge to new situations. When students work in PBL

environments, they are more engaged with both the content matter and with their peers (De Jong 2019). PBL prepares students for life-long learning in a changing world (Dunlap, 2005).

There are numerous benefits to using PBL, with an ever-growing body of empirical research contributing evidence of specific advantages. PBL has been found to encourage students to think about their education with a growth mindset (Iwamoto, 2016). Growth mindset is the belief that a student can improve their abilities on nearly any task through practice and applying learned knowledge from previous attempts at the same task. PBL works for students who learn with a variety of learning styles (Alkhasawneh, 2007). PBL attracts student interest and increases the retention of content knowledge through engaging students in investigations with real-world applications (El-Shaer and Gaber, 2014). PBL is interdisciplinary, combining the use of science, technology, engineering, and math freely while working on projects. STEM PBL can increase student interest in science and retention of content knowledge (Al-Balushi andAl-Aamri, 2014). PBL Increases student content knowledge and depth of understanding (Margaret Holm, 2011). Students demonstrate increased motivation and engagement in PBL classrooms (Blumenfeld & Krajcik, 2006).

PBL has been demonstrated to hold advantages over traditional classroom practices (Almulla, 2020; Sunletha Carter, 2016). PBL teaches students to think analytically about problems (Birgili, 2015). Students emulate real-world tasks and have greater agency in directing their learning (Barron & Darling-Hammond, 2008; Thomas, 2000). PBL has been shown to confer advantages over surface learning through memorization and rote learning (Miller and Krajcik, 2019). Students form stronger schemas for material they cover by experiencing PBL (Almulla, 2020; Miller and Krajcik, 2019).

PBL is a student-centered rather than teacher-centered pedagogical approach, as it focuses on pursuing student interests and embraces students at their ability level and allows them to simultaneously engage in practices that they feel confident in and practices that they need to grow in. In PBL environments, students take agency in the design of their work and the aims of their learning, centered on real-world problems, often identified by themselves. Students are involved in making decisions about their project's topic and can choose topics relevant to their life experiences and interests. Because students have a greater level of influence in determining their education in PBL, they feel more committed to the work required of their projects and take more ownership over their products (Hickey, 2014).

Studies have shown mixed success in using online learning to improve student outcomes, with some studies showing marginally poorer student performance online (Adams, Randall and Traustadóttir, 2015) and others finding marginally better student performance online (Israel, 2015). A meta-analysis comparing online-only school to in-person-only school found no significant differences between learning outcomes for students exposed to either type of environment (Cathy Cavanaugh et al, 2004). Researchers have found that online learning leads to poor outcomes for students when there is a lack of communication between the teacher and student and between students (VanPortfliet and Anderson, 2013). The conclusion is that either online learning or in-person learning can work to provide positive outcomes for students; however, it is imperative that online approaches are combined with otherwise sound teaching strategies (Nortvig, Petersen, and Balle, 2018). The current study seeks to address a gap in the literature through determining effective approaches to applying PBL in an online environment.

While searching for research that exists at the intersection of online learning and PBL, I found a few studies from the early 2000s that shared a few features in common. They tended to

be set in university classrooms and focus on undergraduate students as participants. The studies tended to be set in classrooms that utilized a combination of in-person learning and online learning. Each of the studies that I found focused on some aspect of communication between students working on similar projects.

One study conducted in 2005 investigated the styles of communication that different students used in an online forum used for discussing their projects. This study involved students working in an otherwise in-person environment. The only online component of this classroom experience was group communication about projects. This study found that students with healthy communication styles performed better on group projects than students with unhealthy communication styles (Thomas and MacGregor, 2005). Healthy communication styles are characterized by early and frequent posting in forums, a sense of camaraderie with group members, and high levels of idea exchange. Unhealthy communication styles were characterized by late and or infrequent posting in forums, little connection to group members, slow responses, and low levels of idea exchange.

Another study with a similar design was conducted in 2004. In this study, most of the classroom experience occurred in-person, and students communicated with their own group members in-person. However, student groups communicated with other student groups through posting in an online forum. The study found that groups that actively communicated with other groups co-constructed knowledge, increased students' collaborative skills, and caused higher project performance (Lou and MacGregor, 2004).

While most of the literature that exists at the intersection of PBL and online learning has focused on how to supplement communication between students, the current study seeks to

address some of the challenges caused by the shift away from in-person PBL to a fully online

PBL experience.

Methodology

Choice of Methodology

The current study utilizes action research techniques as set forth by Gay and Araisan

(2003). Action research aims to transform practices in social sciences by combining the

processes of taking direct action in the classroom, and conducting academic research. This

research style creates knowledge through testing novel practices within a given field of study and

then critically evaluating the outcomes associated with those practices. Action research seeks to

address practical problems faced by practitioners and thereby generates data with real-world

applications. In the context of education, action research is engineered to facilitate the

teacher-learning process. The teacher-learning process requires teachers to assess the needs of

learners in their classroom, establish specific objectives, develop and implement plans to meet

those objectives, and evaluate the outcomes of their instruction (Ololube, 2012).

Action research is best utilized under three circumstances: when one seeks to improve

their understanding, develop their learning, and influence other's learning (McNiff and

Whitehead, 2006). Action research is a research design tool that allows the teacher-researcher to

generate new approaches to unique challenges (Reason and Bradbury, 2006). Action research

aims to understand, evaluate, and then change teaching practice to address deficits in teaching

practice and to reach a teaching practice that facilitates student learning in any environment

(Bassey, 1998).

In the Gay and Araisan model of action research, a teacher-researcher reflects on their

own practice to develop an action plan to improve their teaching. An action plan involves

implementing specific strategies to meet specific objectives, typically related to a unique challenge or deficit in a teacher's practice. Then the teacher-researcher continuously monitors and reflects on the development of their teaching practice and the influence of the implemented action plan.

The Gay and Araisan model of action research can be partitioned into 4 significant stages. First, a teacher-researcher identifies an area in their teaching practice in need of improvement. Second, the teacher-researcher develops an action plan to address the area in need of improvement. Third, the teacher-researcher implements the strategies they incorporated into their action plan. Fourth, the teacher-researcher collects observations in their classroom and reflects on the effects of the action research plan they implemented. At the conclusion of this initial cycle of action research, the teacher-researcher uses the insights gained from their reflection on the effects of the strategies they implemented to renew the cycle of research and develop a new action plan to either continue to address the original challenge/deficit or to address an emergent challenge/deficit (Dick, 2004).

While searching for a suitable methodology for this study, I tried to identify what concerns I thought I could address through my research questions. I was interested in identifying the aspects of online learning that could make PBL more successful. Furthermore, I wanted to find an approach that would allow me to build a nuanced and multi-faceted description of the problems associated with teaching PBL online. With these foci in mind, I determined that action research would serve these needs because of its adaptive and reflective nature.

One of the goals of this project was to design a study that could both generate new information and, more importantly, influence my teaching practice and inform the teaching practice of other teachers in similar circumstances. One of the advantages to using action

research in this study is that it allows for focus on the real-world challenges that I was facing in my teaching practice rather than only a gap in educational theory.

Using action research in the current study allowed me to improve my understanding of outcomes in my classroom by investigating the effects of specific strategies intended to ease the transition to online PBL. I was able to develop my learning through improving specific skill-sets related to developing instructional strategies in an online format. Lastly, I was able to influence the learning of my students by developing action plans to address unique challenges and circumstances that arose during the implementation of online PBL curriculum. By utilizing action research, I was able to develop my teaching practice in a way that allowed me to directly respond to my students' and my own needs and deficits.

Action research allowed me the opportunity to continuously monitor my practices and change them to accommodate for student needs (Gay and Araisan, 2003). It allowed me to improve my process of teaching PBL online over time, rather than being confined to a strict set of procedures that were predetermined by my study. The study seeks to understand and improve the process of a teacher shifting from in-person to online PBL instruction. Action research required me to reflect on how my pedagogical strategies were meeting or not meeting my goals and to adjust those strategies over time to continue to get closer to a working model of online PBL.

This research took place in a context where flexibility is necessary because of diverse and ever-evolving student needs. I felt the need to be willing to change my approach to teaching material in particular due to the fact that students are also adapting to a new learning environment and new learning styles. The environment in which this study took place demands that pedagogical approaches can be adapted to fit students needs as new needs emerge. Students

were adapting to new schedules, new reliance on technology in their education, new social dynamics, and new external pressures unrelated to their schoolwork. It is difficult for a teacher to predict the specific circumstances that each student is facing, especially in an online environment, and so I felt it was crucial that I choose a methodology that would allow a greater amount of flexibility in my pedagogy and allow me to change things that were not working as I continue to monitor and reflect on the successes in my classroom. Action research is particularly well-suited for this kind of dynamic environment, where a highly rigid predetermination for the curriculum might serve as a detriment, whereas the highly reflective, adaptive, and reactive nature of action research would serve as a boon.

Context

This study takes place in a small, PBL-focused charter school located in the Twin Cities Metropolitan Area in Minnesota. In addition to being PBL-focused, this school has a focus on expeditionary learning. Expeditionary learning involves students spending time at sites other than the school to tie their learning into real-world applications. There is a low student-to-staff ratio, with 72 students and 14 educational staff. The staff comprised four core-subject teachers, two elective teachers, two special education teachers, four special education paraprofessionals, two office workers, a counselor, and a director.

For the 2020-2021 academic school year, the school made the decision to deliver all content online, presenting a period of dynamic change for the school and the timeframe of this study. This school had no precedent for delivering PBL online. I was the only teacher in the science department and had full autonomy and control over the biology curriculum and how that curriculum would be adapted to an online environment.

The students I served came from diverse backgrounds; there was a high proportion of special education students (45%) and a high proportion of students that received free (6%) or reduced lunch (46%). The demographic breakdown of the student body was 41% White, 37% Black, 13% Latino/Latina, 6% Asian-American, 1% Native American, and 1% claiming two or more races. The student body was 60% female and 40% male. The students scored in the 11th percentile for mathematics scores on a national level, in the 29th percentile for reading scores, and had a 36% graduation rate.

Many of the students at this school came from underserved school districts before arriving at this school. Some of these students were removed from their home district due to behavioral concerns. Most of these students have experienced educational trauma and expressed these concerns to their teachers at this school.

The study took place in a biology classroom over the course of eight units of study. The units addressed were: Nature of Science, Ecology, Structure and Function of Cells, Cell Cycle and Protein Synthesis, Structure and Function of DNA, Genetics, Evolution, and The History of Life. This classroom included students who were returning to the school and had a fundamental understanding and familiarity with PBL in addition to students who were new to the school and had not experienced PBL. The biology course served mixed groups of 9th, 10th, 11th, and 12th grade students. The classroom was entirely virtual throughout the study.

Design

The design of this study is split between the four major steps of action research identified by Gay and Araisan (2003): 1) Identify a problem, 2) Create an action plan, 3) Carry out the action plan, and 4) Observe and Reflect.

Identify a Problem

For my action plan, I identified a set of problems faced by teachers transitioning from in-person PBL instruction to online PBL instruction. The first steps of the study were to identify major potential obstacles to delivering PBL in an online environment and which elements of my teaching practice could be changed to attempt to mitigate the negative effects these obstacles could have on my students' educational experiences. Within each unit that I taught, I identified one element of my teaching practice that I thought could be improved upon through developing a strategy to implement in that unit. Problems were identified through a combination of self-reflection and feedback from students. While selecting problems, I tried to focus on real-world rather than hypothetical problems. I also wanted to focus on problems that could be addressed through a practical change in teaching practice, without demanding a teacher completely shift their approach to teaching. Specific problems I incorporated into my action plan include lack of student-motivation, inability of students to plan use of work-time, lack of student access to space and equipment, students' lack of self-evaluative skills, and student learning disabilities.

Create an Action Plan

Once problems were identified, specific strategies were brainstormed and developed to attempt to address those obstacles. In the course of creating my action plan, I developed a specific strategy for each unit, such as modifying and breaking down certain projects and changing the structure of daily lessons to emphasize working on particular aspects of each project. Because of the ever-evolving needs of students, new strategies continued to be added to the action plan as the school year progressed, and I continued to reflect on what needs my students had that were not being met. I incorporated strategies that seemed to generate positive outcomes into my teaching practice in future units.

Carry out the Action Plan

Carrying out my action plan consisted of implementing specific strategies that were developed for each unit. Implementing these strategies involved making adjustments to what was provided in the online classroom, the approach to instruction and assessment, and how class time was spent. After implementing each strategy, I encouraged students to work on projects so I could develop feedback for them and observe the results of my interventions. As students designed and constructed their projects, I developed a sense of the effects of the instructional strategies I used. As I implemented each strategy, I would reflect on how it affected the classroom, including the effect on student performance and motivation, my ability to write and deliver lesson plans, the amount of time students and I invested in each lesson, the ability to differentiate instruction, the amount of time students invested in work, and how synchronous class time was being used.

Observe and Reflect

As I carried out my action plan, I observed how the strategies I implemented affected my teaching practices. I also observed how my practices adapted to my students' successes and areas in need of improvement. I recorded these observations as notes on my own thoughts and behaviors, field notes on classroom experiences, and analytic memo-ing compiled into a research journal. I also recorded my experiences through writing vignettes to serve as narrative descriptions of mine and my students' experiences during each unit. I reflected on my observations in my classroom to determine the relative advantages and shortcomings associated with each instructional strategy. After carefully observing how each strategy impacted my classroom, I made determinations about how to incorporate or not incorporate those strategies in future online PBL.

Data Collection

  The following sources of data were collected: observation of myself and students, field notes, analytic memo-ing, and research journal entries. The data was collected from the beginning of October 2020 through the beginning of June 2021.

Observations and Journal Entries

  Observations were collected in the form of field notes taken during and after class each day. Particular emphasis was placed on observing the processes engaged in and strategies utilized when constructing lessons. I made small notes on how effective certain strategies appeared to be as they were employed in daily lessons. I recorded interesting incidents and comments made by myself and students. These observations were useful in constructing narratives that detailed the changes I observed in my teaching practice as I employed different strategies throughout the school year.

  A research journal was compiled to record my thoughts and reflections on each day, each week, and each unit. I used this journal as a way to keep track of which strategies I was employing in any given lesson and to reflect on the successes and failures of those strategies. The journal was useful for recording my initial thoughts on the relative efficacy of different strategies and using those notes to steer the direction of the class. After reflecting on journal entries, I often changed the pace, method of delivery, homework expectations, or other features of the class. These journal entries were critical in constructing the vignette narratives for each unit.

  Instructional strategies were the main focus of my research journal. The goal of the study was to find effective instructional strategies, so special emphasis was placed on recording details of how students reacted to different strategies both in terms of what they said about the strategies

I was employing and the quality of the work they turned in after receiving varying instructional strategies. For each strategy I employed, I took notes on how long it was employed, which assignments or projects to which it was relevant, notes on student attitudes and performance, and whether or not I deemed the strategy to be useful. The strategies that were deemed most useful continued to be used throughout the course of the study and had the most data recorded on them.

One of the recurring categories of observation in my research journal was changes to classroom structure. Especially at the beginning of the study, I was regularly taking notes on adjustments I made to the pace of curriculum, how synchronous work time was spent, and how I delivered material to students. I took notes on how changes in the pace of curriculum affected student motivation and breadth as well as depth of learning. Notes were taken on how daily class time was used differently in different units and on the successes and areas for improvement associated with different approaches to using synchronous work time.

Data was collected on changes made to daily homework and formative assessments. Many homework assignments were left out, freshly developed, or altered to adapt to changing student needs. I recorded notes on the changes I made to each assignment within my research journal. I took notes on student performance on different assignments over the course of the study, indicating which assignments with which students saw the greatest successes and which assignments caused students to struggle the most. For each homework assignment, I recorded the scores of high-performing students and the scores of low-performing students, average scores, and the rate at which students turned in the assignment. I also recorded notes on how engaged I perceived students to be with each assignment, which assignments seemed to be enjoyed most by students, and which assignments seemed to cause the most frustration or anxiety in students.

Notes and reflections on the successes and areas of improvement for projects made up a significant portion of my research journal. For each project, I recorded any changes I made from how I would normally administer the project in an in-person learning environment. I recorded notes on different approaches I saw students take for each project. Notes were taken on how many students successfully completed each project. Specific concerns expressed by students about particular project designs were recorded. For each project, I recorded the number of students that successfully completed the project and how long students took to complete the project. I asked students to provide me with a short list of pros and cons as part of their self-evaluation for each project.

Analytic Memo-ing

As I recorded my thoughts and reflections in my research journal, I began having thoughts on the interpretation of the data. I employed analytic memo-ing to take notes on my journal entries. Analytic memo-ing is a research technique used both to generate and interpret data by recording reflective notes on the raw data that is collected in a study (Birks, 2008). These notes can be used as data themselves and also serve as the basis of initial interpretation of data. I used analytic memo-ing to generate data by recording my initial thoughts and reactions to the data collected in my journal entries. These initial thoughts and reactions would form the basis for how I shifted my pedagogical approaches and developed instructional strategies between each unit. I recorded what I thought was the main takeaway lesson from each journal entry and how those points may make their way into the interpretation of my data.

Data Analysis

The following section outlines how I analyzed the data collected in this study and the ways in which that data was organized. The data was placed into one of three categories: Online

PBL instructional strategies, broad changes in my teaching practice, and narrative vignettes of

each unit taught. After segregating data into these categories, I familiarized myself with the data

I collected in each category. Each category was then subjected to a deeper level of analysis using

the Costa Qualitative Data Analysis (CQDA), a type of thematic analysis and code development

(Costa, 2019), to find themes and create categories within each cluster of data. In CQDA, codes

are shorthand labels applied to passages in data that aim to capture the ideas or feelings

expressed in a given passage. In addition, CQDA themes are broader than codes and generally

incorporate multiple codes that appear frequently and share attributes. Themes represent larger

patterns identified in the data. The data analysis techniques presented here helped me to answer

my research questions through the use of a consistent approach to thematic analysis of qualitative

data.

I used the CQDA approach to familiarize myself with the data, create deductive and

inductive codes, and then sort and categorize those codes. Deductive codes were derived from

the research questions this study aims to answer to help in the following ways: identify points in

the data that demonstrate design and delivery of online PBL instruction in a secondary science

classroom, modification of PBL for instruction, and the similarities and differences that exist

between the delivery of PBL online and in-person. Inductive codes were derived from significant

statements in the data to link specific classroom practices and PBL instructional strategies to

deductive codes and recognize themes and patterns in the data that elucidate the answers to the

research questions of this study. Once the deductive and inductive codes were established I

sorted and categorized these codes to generate themes.

Themes were identified from these codes by first determining which codes appeared most

frequently throughout the data. The codes which surfaced most frequently formed the basis of

the themes. To generate the themes, codes were placed into clusters based on similarities. For

example, the codes "autonomy", "self-paced", "motivation", and "awareness of abilities"

appeared frequently and shared important features and attributes, so these codes were used to

generate the theme "Independent Work." I used the themes that emerged in each category of data

I collected to categorize the PBL instructional strategies I implemented into eight categories and

the broad changes in my teaching practice that I implemented into eight categories.

The analytic memos I recorded to accompany my research journal helped me identify

trends and patterns in my data as they emerged. These memos formed the basis for the grouping

of different strategies that I found most useful in the transition to online PBL. After familiarizing

myself with the data I created codes to help cluster similar strategies together. I searched for

themes in these clusters of strategies that emerged through the course of the study. After

developing themes, I used them to organize the strategies I used into eight distinct categories.

These strategies are (a) develop a lab that can be conducted independently by students, (b) assign

mini-projects that require students to incrementally complete the work required for a larger

project, (c) provide a daily checklist for students to consult as they complete a project, (d) model

how to construct the product for a project day-by-day by completing the same tasks that they are

required to complete (e) using breakout rooms and forum discussions for small-group

collaboration, (f) provide alternative projects so students can demonstrate mastery using multiple

modes of learning, (g) provide students with work samples and have them rank the work samples

to guide them towards a higher quality project, and (h) break group projects into discrete tasks so

each member of a group has specific roles and tasks to complete. Each of these categories

represents a group of strategies that teachers can use to aid in the transition from in person to

online PBL. This data can be used by future in-service teachers to plan curricula in an online

PBL classroom.

Next, I familiarized myself with the data I collected on broad changes in my teaching

practice. I created codes and searched for themes in broad changes in my teaching practice

between teaching in person PBL and online PBL. I organized the changes that I observed in my

teaching practice into eight categories. These categories are (a) projects, (b) driving questions,

(c) group work, (d) synchronous work, (e) asynchronous work, (f) pace of curriculum, (g)

delivery of material, and (h) feedback. I then created a table to make connections and

comparisons between each of these aspects of my teaching practice in-person and online. The

purpose of this table is to help future in-service teachers understand some of the adjustments they

may have to make to their practices when switching to an online PBL format.

To aid in explaining the ways that strategies were implemented in different units

throughout the course of the study, I constructed narrative vignettes for three units I taught in my

biology class. The units I constructed vignettes for are the nature of science unit, the ecology

unit, and the evolution unit.These three units were selected to illustrate the development of my

action research during an early unit, a mid-year unit, and a unit near the end of the year. The

action research process was utilized through all eight units of the course. These vignettes give a

brief synopsis of my approach to teaching the three selected units including any major changes in

classroom structure, homework, projects, and the strategies that I employed to ease the transition

to online PBL. These vignettes are presented in the results section. I synthesized observations,

journal entries, and analytic memos to create the narrative vignettes. The narrative vignettes

contain specific information about projects that students completed through the course of the

study and how various instructional strategies impacted successes and failures in the classroom

in specific ways. The goal of creating these vignettes is to give a narrative description of what the online PBL experience was like for the teacher and the students during each unit.

<div align="center">**Results**</div>

From the findings a set of themes emerged associated with a successful online PBL classroom. The themes presented are foundational to the strategies developed to help teachers transition their PBL curriculum to an online format. A mix of individual and group work, along with modeling, chunking, and self-evaluation were key elements of successful implementation of online PBL.

Theme 1: Individual Work

Through analysis of the research journal, codes such as "autonomy," "self-paced," "motivation," and "awareness of abilities" fell under the theme of individual work, meaning students needed to do their own individual projects.

Individual projects consisted of students familiarizing themselves with the driving questions of the project, designing their project or using teacher-designed projects to address the driving question, conducting their project, developing and sharing a product, and then reflecting on their work and achievements. The majority of students opted to use teacher-designed projects and expressed their mastery over concepts through the development of their products. These projects were completed by each student with check-ins, discussions, and guidance from the classroom teacher and paraprofessional. Due to the asynchronous nature of student work-time during online learning, projects needed to be designed in such a way that students could conduct the bulk of their project autonomously, without direct supervision by their teacher and without the use of school facilities.

I saw students take greater agency in projects that they carried out individually. Through having students conduct their own projects they were able to practice independent learning and practice working through each stage of solving a problem. Having students complete individual projects addressed students' concerns over being able to effectively communicate and cooperate during distance learning. By providing students with opportunities to do individual projects students were able to demonstrate their own mastery over concepts and mitigate anxiety about the poor performance of others negatively impacting their score.

Theme 2: Groupwork

A second theme that emerged was groupwork and the codes associated with students completing group projects appeared in the data after students had experienced individual projects. These codes included: "accountability," "social learning," "discussion," "communication," and "collaboration."

Students were given the opportunity to work together on certain projects to facilitate social learning, practice communication, exercise their strengths, and facilitate growth in their areas of weakness. For group projects students went through the same steps as individual projects, however certain tasks like research and construction of the product were often divided in such a way that students focused on different areas. Group projects involve unique steps, including the development of a student-designed group contract, as an agreed upon set of rules and standards of behavior during the course of the project, evaluating group members' performances, and preparing for group presentations. Through the completion of group projects students were able to exercise their strengths and improve upon areas of weakness, although some students did use group work to avoid areas of improvement.

Students expressed interest in working in small groups so they could pool their knowledge and distribute their work loads. Students engaged in social learning and benefited from being taught by their group members and vice versa. Group projects allow students to reap the benefits of Vygotsky's Zone of Proximal Development (Vygotsky, 1978). By pairing higher achieving students with moderately lower performing students the moderately performing students are able to improve their achievement level by observing, communicating with, and learning from the higher performing students. The higher performing students also benefited from this relationship because it created an opportunity for them to practice iterating what they have learned. Both students are able to view the material through more dimensions than before working together, giving both parties new insights, perspectives, and approaches.

Theme 3: Modeling

Codes like "examples," "outline," "tasks," and "demonstration" highlighted the need for scaffolding in the online environment and revolved around the theme of modeling behaviors and products to students. Modeling took the form of demonstrating how to navigate each step of project design and each step of product construction as well as showing students examples of completed products

As students began the design of their project they would have to consider how they would construct their product. I provided students with a wide variety of examples to use as models in the development of their products and I provided more examples during online instruction than I typically would during in-person instruction. I wanted students to understand the wide variety of approaches someone could take to designing different projects and products that answered the same driving questions and met the same goals. Examples were presented in synchronous class periods so that I could explain them and answer any questions students had. I

provided product examples through Google classroom so that students could access them while

working asynchronously. When applicable students were also given external links to websites or

videos that featured examples of similar projects.

In addition to showing students examples of completed products, I also modeled how to

construct products step-by-step. Students were shown how to collect materials, design a product,

build models, take pictures, record video footage, and write paragraphs and stories to develop

various project artifacts. Each day of the project I modeled for the students would be shown how

to complete a different element of the project.

Theme 4: Chunking

The theme of chunking represents separating large amounts of information into smaller

more manageable chunks. Chunking is an important process in PBL, especially in the context of

online learning. The codes associated with chunking included "mini-project," "break down

instruction," "daily task lists," and "steps." Large projects were chunked into smaller projects

because students expressed frustration over needing to remember complex routines and complete

multi-step projects without clear delineation for each task involved. Requiring students to

complete incremental steps towards a larger goal. Chunking took several forms in the online PBL

classroom, from breaking projects down into discrete tasks, decomposing larger projects into

mini-projects, to providing daily task lists for students.

Many students, in particular special education students, expressed the need for help

breaking the sequence of completing a project into discrete tasks that could be tackled and

accomplished individually to avoid fatigue, disinterest, and burnout. One of the entry documents

that students were given at the beginning of a project was a paper that outlined each of the major

steps that needed to be completed to finish a teacher-designed project and when applicable those

major steps would be broken down into specific tasks that could be completed in a relatively

short amount of time. These documents served two purposes, first they helped students account

for the work they had to complete by checking off individual tasks as they were finished, second

they provided students with daily task lists so that students could plan out how they would use

their work time during each project work day they were given.

      During group projects students used the entry documents to divide work equitably among

group members. These discrete tasks helped individual group members understand their specific

obligations to the group. Each task could easily be compared to other tasks so that students could

opt to take on tasks that they felt comfortable with, were suited to their strengths, or would help

push their boundaries in an area that they wanted to develop. With groupwork partitioned in this

way, students were able to exercise agency in creating an equitable groupwork experience for

themselves and their peers.

      Another area where chunking became important was redesigning larger projects into

smaller mini-projects. Each of the mini-projects would serve to have the students complete a

major step in the larger project. Decomposing the project into smaller elements created a

lower-stakes atmosphere where students could complete one mini-project, receive feedback on it,

and adjust their project design more readily than when working on a larger project. In this way

students were able to demonstrate their mastery over concepts incrementally, without feeling

overwhelmed by the expectation of completing one large project with one due date.

      Chunking overlapped with modeling as students were shown how to complete projects

through demonstration of the steps that they need to complete for each day. While students were

presented with an example of how to complete each task they were also presented with a model

for how to chunk the project into smaller tasks. In this way chunking and modeling were tightly interwoven.

Theme 5: Self-Evaluation

Students should be evaluating their own work and reflecting on their achievements in order to refine their project design and produce a quality product; the theme of self-evaluation captures a critical element of PBL. Codes that lead to this theme include: "rubric," "project design," "reflection," "refine," and "improvement." Students were required to do some form of self-evaluation for every project and this usually took one or more of three forms: students evaluating samples provided by the teacher to compare to their own work, students developing their own rubrics, and/or students using their rubrics to evaluate their performance.

At the beginning of a project students were given many examples to examine and use for inspiration in their own project design. When students were tasked with evaluating project samples, they ranked them as "high quality," "average quality," or "poor quality." Students were then able to compare their project designs to work samples of varying qualities and make decisions about how they would design and redesign their projects to meet higher standards of quality.

Having students design their own rubrics was integral to self-evaluation because it required students to engage in higher-order thinking tasks like critical analysis, evaluation, and incorporating feedback. Students designed their rubrics before constructing their product so they would have a framework to guide their efforts and a way to personally account for the quality of their project as it was developed. Students were able to use these rubrics to score their own performance and the quality of their finished projects. This helped students understand teacher feedback and helped students understand how they earned a specific grade and what they could

do to change their project to increase their score or performance on a future project. Through the use of a rubric with specific criteria students could easily identify the weakest points in their project and find areas in which to refine their project and demonstrate their mastery over material.

Broad Changes in Teaching Practice

Over the course of the school year, I found myself changing my approach to many aspects of my teaching practice. I identified nine major areas of my teaching practice that experienced significant change in the online environment. Table 2 compares and contrasts the different approaches I took across those nine areas during in-person PBL and online PBL.

Table 2

Comparing Broad Changes in Teaching Practice Between In-Person PBL and Online PBL

Topic	In-Person PBL	Online Learning PBL
Projects	Students complete projects independently and in groups within the classroom. Most project work time is given after a lesson. Students are given immediate feedback daily on their project's progress. Students are expected to respond in-person to the feedback they are given.	Students complete projects independently and occasionally in groups. Students complete projects outside of the classroom, with very little work time during synchronous class periods. Synchronous class periods are used to model the completion of projects. Students are given feedback through Google classroom and receive less immediate feedback. Students are expected to respond online to the

		feedback they are given.
Driving Questions	Students were given more independence in developing their driving questions. Or students were given the same driving questions but allowed leeway in changing the questions to meet their specific project designs. Students were allowed to develop their own products and procedures, with suggestions from the teacher.	Students were given the same driving questions. Students rarely asked to adjust the driving question. Students needed more direction and less autonomy. Students were given goals for their projects including products and procedures. Students were allowed to give input and adjust their product and procedures but most students chose not to.
Group Work	Students were given regular and frequent in-class groupwork time. Most daily lessons included groupwork activities. Students signed group-contracts before engaging in group-projects. If students struggled to work in groups then teacher-led interventions would take place. During these interventions	Students did less groupwork. Most groupwork was in large groups. Either half of the class worked with the teacher and half of the class worked with a paraprofessional or the entire class worked together. Towards the end of the school-year students were given more asynchronous group-work. Students signed group-contracts before engaging in group projects. If students struggled to

	students would be in the same place and expected to discuss their disagreements.	work in groups then teacher-led interventions would take place through Zoom meetings, Google Meets, or email. These interventions were far less effective than in-person interventions. Some group members would either not show up or not participate in the discussion.
Synchronous Work	Students were meeting synchronously every school day. Nearly all formative assignments were expected to be completed in class, usually in groups. Students completed homework assignments without strict supervision,	Students only met synchronously twice a week per class. Most of the time that we met synchronously in my classroom was spent reviewing homework assignments. These meetings were used as an opportunity for students to ask questions as well as a chance for me to give immediate feedback on how to complete each assignment. Students had much closer supervision to prevent students from becoming misdirected.
Asynchronous Work	Students completed little work asynchronously. Students were given project work time during class but could choose to continue	Students were given a great amount of asynchronous work time. Because classes were only meeting twice a week synchronously, students had every other

	working on projects asynchronously out of class. Students were given "unit questions" to complete outside of class for each unit. These inquiry based assignments required students to consult their textbook and online resources to come up with answers to content questions and essential questions related to each unit.	day to work asynchronously on each class. Most of the project work time that students had was asynchronous. Students were given homework assignments before class so they could make first attempts at homework asynchronously, however students were aware we would review all homework synchronously.
Pace of Curriculum	Each unit consisted of 2 lectures split across 4 or 5 days with daily activities interspersed with lectures, 3 formative assessments, and 1 summative assessment in the form of a project. Each unit lasted approximately 4 weeks, 2 of which were typically reserved for completing the project.	Each unit consisted of 1 lecture split across 2 or 3 days, with a heavier emphasis on daily activities interspersed with lectures, 2 formative assessments (the unit questions were not used), and 1 summative assessment in the form of a project. Each unit lasted approximately 4 weeks, 2 of which were typically reserved for completing the project. About halfway through the year I began introducing the project at the beginning of each unit so

		that students would have increased work time and time to ask questions.
Delivery of Material	Nearly all instructional material was delivered as whole class instruction. All materials that students were expected to have were physically distributed in class. Lectures involved more and answer components. Lectures were not available for review at a later time. Students could request copies of the slides that I used, and special education students were given copies without asking. Students could easily be pulled aside or out of the classroom for one-on-one instruction with either the teacher or para.	All instructional material was delivered either through either synchronous meetings on Google Meets or asynchronously through Google Classroom. All lecture materials, notes, and homework assignments were made available before students needed them on Google Classroom. I started to pre-record my lectures so that students could review them independently. For certain struggling students I arranged one-on-one video meetings to review material with more supervision and guidance.
Feedback	Feedback was provided to students in person and through writing on returned assignments and rubrics. Students received	Feedback was provided to students through google classroom and one-on-one online video meetings. Students submitted formative and summative

	more real-time feedback. When students made mistakes while engaging with material their approach was immediately redirected. Students asked more questions and were given more direct answers about concepts they felt confused about.	assessments through google classroom where the teacher could view their material and leave comments. Students would receive comments on specific portions of their work indicating that they had completed it correctly or incorrectly. Students would be directed to specific resources to consult to gain mastery over topics that they failed to demonstrate mastery over. Students also attended one-on-one online video meetings to discuss specific homework assignments or projects. In these video-meetings students were able to get real-time feedback and discussions that better mirrored in-person feedback without the entire class present as an audience.
Assessment	Assessment of student work took place after assignments were physically handed in by students. Most assessment took place through notes directly recorded on	Assessment of student work took place after assignments were turned in digitally. Most assessment was recorded through comments on Google Classroom. Student grades were derived the same way across

	student work. Student grades were derived the same way across all classes according to school policy. Student grades were composed of two components: 70% of the grade was derived from summative assessments (projects) and 30% of the grade was derived from formative assessments (homework).	all classes according to school policy. There was a shift in our policy to determine grades with a heavier emphasis on formative assessment. Student grades were composed of two components: 50% of the grade was derived from summative assessments (projects) and 50% of the grade was derived from formative assessments (homework).

Nature of Science Vignette

Introduction of Nature of Science Vignette

The first unit I teach in my biology class is a "Nature of Science" unit and I introduce students to measurement, the metric system, the Next Generation Science Standards (NGSS) Science and Engineering Practices, and different disciplines in science like chemistry, environmental science, physics, geology, and biology. The summative assessment for this unit is a project in which students use the NGSS Science and Engineering Practices to design an experiment. Students adjust an independent variable in a lab exercise and predict the effects of their independent variable on the dependent variable. I had to make broad adjustments to this unit while teaching this class online. The schedule and structure of daily class was adjusted, the

pace was slowed, and I substituted a different project in lieu of the project I would normally

assign.

Project: Nature of Science Unit

I use the project for this unit as an opportunity to learn lab skills. This project has

students exercising lab safety skills and measurement skills in addition to actually investigating

the scientific method. With online learning I was unable to use lab equipment so I had to

improvise and figure out how students could manipulate variables using materials they had at

home.

In a regular school year when teaching students in-person I do a lab exercise where

students take a certain quantity of applesauce and they add the enzyme pectinase with the goal of

manipulating a variable so that they can produce the greatest quantity of apple-juice possible..

Students change one variable, which could be the temperature of their applesauce, the filter they

use to extract their apple juice, a solute that they add to their applesauce, or a variable they

choose. For online learning I had to redesign my project, swapping out the applesauce lab for a

paper airplane activity. I gave students a paper airplane design to use as a control. Then I asked

them to modify that design, treating the modification as their independent variable and flight

distance as the dependent variable. I asked all the students to fly their paper airplanes and

measure the distance that the airplanes could fly both with the original design (control) and the

modified design (variable). After collecting data on flight distance of various paper airplane

designs, students calculated the average flight distance for each design, plotted the data on a

table, and wrote a brief lab report explaining their airplane design and findings.

The airplane project still allowed students to practice making measurements and using

some of the same tools they might use in a laboratory setting, however they were not able to

practice lab safety protocols at all. I think they missed a big sense of what it feels like to do an experiment in a lab setting. I think for some students this paper airplane project felt silly and they did not give it the same seriousness that they would give it if it were in the physical classroom.

Homework Assignments: Nature of Science Unit

At the beginning of the school year my approach to homework was to use the same exact assignments as I had used during in-person learning and tried my best to create a facsimile of what I would do in an in-person environment. I quickly learned that I would need to make certain adjustments to how I was presenting information to students and how I was expecting students to engage with that information.

One of the assignments that I tried to use during my first unit that influenced my approach was a set of unit questions on the nature of science. This assignment requires students to independently research the answer to certain questions before we go over the material in class. This helps students practice independent investigation and gives students the opportunity to form schemas around the concepts we are working on before I prescribe any perspectives to them.

When I assigned the unit questions online students had difficulty completing it, citing stress and confusion caused by investigating science concepts before they had received direct instruction on those concepts. It is typical for students to express doubt about their ability to complete these assignments, however typically most students succeed at completing this assignment. During the online experience nearly all of my students told me that they did not feel they could complete this assignment within the timeframe they were given. I realized that I needed to simplify the assignments I expected students to do independently and remove any ambiguity. While I believe this assignment is a great exercise in independent work, I realized that my students were facing an unprecedented level of independent work in all of their classes and

that pointedly forcing them to exercise independent work had become somewhat pointless. They would be exercising a greater level of autonomy regardless of how the assignments were structured, and by providing too little scaffolding with this assignment students decided to give up before they had even started. At this point I made the decision to remove the unit questions from each of the units I was teaching and find other ways to have students engage with the material with slightly more guidance than they would receive through working on the unit questions.

The next assignment I tried with my biology class was a T-chart graphic organizer where students needed to record the focus of different major scientific disciplines. This assignment required far less independent research than the unit questions, although it did require students to take careful notes on what we discussed in class and possibly do some independent research to fill in the gaps of what they may have missed. I saw a greater level of participation from students for this assignment. Far more students attempted the assignment, although many students turned in partially completed assignments and some students turned in nothing. I was disappointed at this because this assignment was relatively simple and required far less effort than the unit questions had. I was glad to see that by providing more scaffolding I was able to dramatically improve student participation, however I realized that students still needed more time and guidance adjusting to working independently.

I gave my students an assignment to practice metric conversions where they were given different values of measurements with different metric units. Students were asked to convert the measurements from one metric unit to another metric unit, for example convert kilometers to meters. I decided to approach this assignment as an in-class group activity. I guided students through several examples after giving the instructions. Then I had students complete a small set

of problems independently and asked for students to share their answers. The students worked

through the entire assignment in class, completing sets of approximately five problems before the

entire class checked in. During check-ins students shared their answers, discussed some of the

common mistakes, and each of the correct answers. I think by completing this assignment

together as a class students gained some confidence about how to work online. Working as a

group gave me the opportunity to see some of the mistakes that students were making and

answer more of the questions students had about working online.

     During the Nature of Science unit I realized that assigning the same assignments online I

required of students during in-person learning was not working well. One reason was that during

online learning students were establishing all new sets of norms. Students were learning how to

work independently, manage their time, create digital documents, and more. I realized that many

of the tasks I was asking of students were requiring them to do much more cognitive work than

simply engaging with the biology material that I actually wanted them to engage with. They were

spending more time figuring out online learning than they were learning about the biology

content. Because students were spending so much time learning this new approach to their

education I realized that I would need to slow down the pace at which I was assigning work. This

made me realize that I would run out of time to have students complete their project work before

the end of the unit. The solution I came up with was to start having students complete the steps

that would bring towards the completion of their project as homework assignments. By taking

this approach I was able to more closely guide students in the beginning steps of each project as

we worked through homework assignments in class together. This approach also helped me use

class time efficiently because students were both completing homework assignments and laying

the foundation for their projects at the same time. I was also able to help ease students' transition

into working online because we were able to have a more vigorous back and forth discussion about the difficulties that students were facing as they attempted to complete assignments independently.

The next few assignments I gave students revolved around practicing the skills needed to complete the project for the nature of science unit. The first of these assignments was having students design their study by identifying an independent variable to test and a dependent variable to measure. Then students had to construct a hypothesis with both of their variables. For example a hypothesis might read "As the width of the paper airplane's wings increase, the flight distance of the paper airplane will increase." I was able to give immediate feedback to students on their experimental design because they were doing this aspect of the project as homework

The second assignment asked students to construct a data table to record the flight distance of their paper airplanes during trials. For each trial the student was required to toss their paper airplane and record how far the paper airplane flew in a straight line from the point where it was released. Students had to first construct the table itself, including labels for the number of trials they were doing, their independent variable, and their dependent variable. After completing each trial the students recorded the data they collected. Students calculated the average flight distance for each airplane they tested. I had students complete the airplane assignment of recording data and calculating averages instead of another formative assignment so that students could use this data for their final project, thereby reducing the demands on student time and energy.

The last step of the project that students completed as an independent assignment was to create a graph plotting the data they collected on average flight distance for each of their airplane designs. Students first had to use the data they compiled in their data table to practice calculating

averages. Once students had the average flight distance for each design calculated they

constructed bar graphs representing their findings. Students wrote a conclusion about whether or

not the data they collected supported or rejected the hypothesis they developed for their

experimental design. After students finished this assignment they were given the instructions for

their project, which involved them using the skills they had practiced by completing the past

three assignments as well as the data they collected and analyzed to write a lab report on their

experiment.

Generally, I assigned less homework for this unit than I would during in-person learning.

The homework that I did assign was reviewed more thoroughly in class. One of the innovations I

implemented was to use pieces of the project as a substitute for homework. By assigning less

homework I was able to decrease the amount of stress students were going through and also

decrease the effect that transitioning to online had on the pace of my curriculum. By conducting

in-depth reviews of assignments in class I was able to ensure that students were forming accurate

conceptions about the material and increase student participation. By substituting pieces of the

project for homework I was able to efficiently direct students' time and attention to creating a

high-quality product that demonstrated mastery over measurement and experimental design.

Activities: Nature of Science Unit

As I contemplated how to implement in-class activities I was taking lessons away from

what I had experienced with my earliest attempts at homework assignments. In an in-person

environment one of the first activities I did with my biology class was a group presentation on

lab safety protocol. I typically would ask students to research lab safety protocol and choose one

thing to focus on, for example how to handle a spill. Each group would present on their chosen

element of lab safety and I would give a short follow-up presentation to cover any gaps not

covered by student presentations. Due to the fact that students expressed hesitancy about working in groups and were struggling with the assignments I had already given them and I had to spend a great deal of class time following-up on those assignments I decided that I needed a way to expedite this activity. I decided that I would create a comprehensive explanation of lab safety procedures and spend class time doing the presentations that normally would be done by students. I believe this was a faster way to convey the same information to students, although I do think students lost out on the richness and depth of learning that comes from constructing their own explanations of lab safety. After I had delivered my presentation on lab safety to the students, I realized that if I had recorded the presentation it would be more valuable to students as they could review any important information they had not fully grasped during my in-class presentation and students that had missed the presentation would still have access to the instructional material.

Another key activity that changed was a documentary that I typically showed students to help illustrate how a body of research is used to synthesize a scientific theory, and the level of scrutiny that goes into producing the evidence for a scientific theory. In an in-person learning environment I would show students a documentary produced by the IPCC on climate change. I would pause the video frequently to discuss the evidence that they are using, their methods for producing that evidence, and how that evidence comes together to form a scientific theory. One drawback to this documentary is that it is very information dense and has a dry delivery style. In an in-person environment I can break up the dryness of the delivery by fostering class discussion about the evidence they present. However, in an online context I was not sure how to approach this same instructional material without leaving students feeling bored, so I decided to take a different approach to illustrating how evidence is compiled to construct a theory. For my online

course I had students watch a shorter documentary on the extinction event that killed off

dinosaurs 65 million years ago and had students watch an episode of Ancient Aliens that

postulated different reasons for the extinction.. I had students record the evidence provided by

both sides and then evaluate what they thought of each side's evidence and whether or not it

would qualify as a scientific theory.

Instructional Material: Nature of Science

Another area where I made adjustments to my nature of science unit is how I delivered

instructional material to students. During in-person learning I would devote one or two class

periods a week to longer lectures, sometimes using nearly the whole class period for direct

instruction. Students were provided access to my slideshows upon request, and special education

students always received a copy. During online learning I decided that I needed to reduce the

amount of time that I spent lecturing, both because of waning student attention spans and

because of the limited amount of synchronous meeting time available. I started giving shorter

lectures between 15 and 30 minutes long nearly every day that we met synchronously. I provided

all students with copies of my slideshows along with guided notes through Google Classroom. I

also provided supplemental material including links to Youtube videos, readings, and access to

some longer documentaries that I would often show in-person but chose not to show during

online class time.

Summary: Nature of Science

The nature of science unit was the first unit that my students worked on in the new online

environment. Students were apprehensive of change. I tried various strategies to scaffold the

online learning experience. Some of the strategies that I found most useful included giving

shorter and more frequent lectures, opting to complete homework assignments as whole class

activities, and creating a project that students could complete remotely and asynchronously. Both the students and myself were adjusting to the new environment and determining what would work for us. Many of my teaching practices began in a similar way to what would be done in-person but had to be modified; most notably my classroom experienced a significant reduction in pace and volume of work. This trend would continue with future units.

Ecology Vignette

Introduction of Ecology Vignette

The second unit I teach in my biology class is an ecology unit. In this unit I introduce biological communities, ecosystems, biomes, the flow of energy and matter through an ecosystem, ecological relationships, trophic levels, biogeochemical cycles, and population biology. The summative assessment for this unit is a project in which students synthesize several sources of information to construct an informative product on the impacts of litter on a biological community. The adjustments I made in this unit were less far-reaching than the adjustments I made in the initial unit. Major adjustments made in the ecology unit include breaking a large project into mini-projects, redesigning group activities for individual students, conducting in-depth reviews of homework assignments, and reducing the amount of time students were expected to pay attention to instructional material.

Project: Ecology Unit

I use this project as an opportunity to have students practice the steps of PBL and place special importance on the design and research steps of PBL. Students are required to investigate a piece of litter found in their environment and create an artifact that displays the effects that the litter has on biological communities.

Typically, I would begin this project with a day of service where I take students to a local park to clean up litter. Each student selects one piece of litter as the focal point of their project and begins conducting research on that litter, including the materials it is made from, how long it takes to decompose, which organisms it affects, and ecological impacts of producing the item. Due to the asynchronous and no-contact nature of online learning I did not have students pick up litter in the online rendition of this project. Instead students chose from a list of common litter or sought approval to research a different piece of litter. During in-person PBL I would have students complete the following three mini-projects as one larger project with multiple steps of research but only one final product.

Once students chose their piece of litter, they were tasked with a mini-project in which they conducted research and created an informational poster about their litter. Students used research guides to frame their independent research into general facts about their litter and the impacts it has on ecosystems around the world.

While completing the first mini-project, students generated a list of animals and plants that are harmed by the litter. This list serves as the segue into the second mini-project, in which students must choose one of the affected organisms to become the focus species for their project and begin investigating the ecosystem which that organism lives in; its niche, habits, range, population, and ecological relationships. Students produced another informational poster or visual display of information, this time on the focus species.

The third and final mini-project requires students to delve deeper into the ecological relationships between their focus species and three other organisms. First students must identify at least three other organisms that share a direct ecological relationship with their focus species, often these organisms have a predator/prey relationship or engage in symbiosis with the focus

species. Students must use evidence from their first and second mini-projects to describe the

negative effects that litter has on the focus species and how the negative impact on the focus

species ultimately harms the organisms that share ecological relationships with the focus species.

The product for this project is typically a slideshow that students present to the class. I did not

require students to present their slideshows directly to the class, however I did have students

publicly upload their slideshows so other students could see them.

Homework Assignments: Ecology Unit

During the Ecology unit, I decided that every formative assignment I assigned would

provide students with key background information and skills directly related to one step of

completing the project. I had students complete mini-projects to collect that information, unlike

the first unit, I did not give the students formative assessments to collect information that would

ultimately go into their final project. Instead the formative assessments were built into each step

of the unit.

The first assignment I had students complete for the ecology unit was a guide on the

impacts of litter, specifically focusing on where litter ends up and how long it takes to break

down. Students examined the "life-cycle" of several common household items that frequently

become litter. For each piece of litter students had to record key points of information. The

students answered five reflection questions after recording information on each piece of litter.

Students used this assignment to inform their independent research into the type of litter their

project focuses on while completing their litter research poster. Completing this assignment gave

students a sense of what key pieces of information they would need to identify about the litter

that they chose to focus on in their final project.

As I designed formative assessments for the ecology unit it occurred to me that my students would benefit from the creation of new assessments that were not parallel to in-person assessments but instead narrowly focused on the concepts and skills students needed to complete their project and were designed to be completed online only. To this end I designed an assignment on biological communities. Students read a passage and then had to explain the relationships between interdependent organisms and explain real-world examples of ecological destruction caused by the loss of keystone species. This assignment was intended to get students thinking about what will happen to the biological community that they are focusing on in their project. As they developed their slideshow, they explained how the effect of litter on one species can have negative consequences for other organisms interacting with that species in the same environment.

I knew that students were not always spending time seriously reviewing the feedback I was leaving on their assignment in Google Classroom. To address this problem, I started doing detailed reviews of homework assignments in our synchronous class so students could understand what was expected and the takeaways and important concepts covered in each assignment. After I started doing in-depth in class reviews students began turning their homework in more frequently and then correcting their own homework after the reviews.

Activities: Ecology Unit

For this unit I shifted away from having students spend time and energy on independent homework and did more in class activities that were ungraded to expose students to the concepts and skills they would need to complete their project. I decided that for this unit I would try to branch away from activities that I would normally do in an in-person environment. I had decided that I needed to find ways to communicate the same concepts that were more tailored to the

online environment, rather than trying to force something designed for in-person learning to fit into an online environment.

In an in-person environment one of the activities I have students engage in for the ecology unit is a group activity in which each group is assigned a specific biome that they then must research and illustrate. Once each group has created an illustration of their biome with a bullet point list of defining characteristics of their biome, students hang their illustrations around the perimeter of the classroom and the class engages in a gallery walk so that each student can learn about each different biome. I was not sure how to emulate the gallery walk as we began this unit so I decided to have students complete an activity where each student would cover each of the major biomes independently. Students completed a modified T-chart graphic organizer with a section devoted to each of the major biomes where they created smaller illustrations of each biome and recorded a bullet-point list of key features of that biome on the opposite page. In this way students were still exposed to the same information, however they did miss out on depth-of-learning and opportunities for social learning.

Another activity I have students engage in during in-person learning that involves a gallery walk is a group activity where students build a food-web. Students work in small teams to research ecosystems in a specific biome and then construct a poster illustrating the relationships between different organisms in the ecosystem. After each poster was constructed students would do a gallery walk to familiarize themselves with food-webs across a variety of biomes. I wanted students to work at constructing a food web, however I knew that many students still were not comfortable working in groups and many students were still struggling with producing physical artifacts like posters. For the online environment I developed an activity where students wrote a short story about an organism living in a specific biome. Students had to

research the biome to know what kinds of food sources might be available to the organism they were writing about, what kind of habitat their organism might live in, and what other types of organisms they would be interacting with. Students wrote a "day-in-the-life" style story about any organism they wanted to choose and had to include details about how the organism gained energy, the predators it had to avoid, and if any predators succeeded in capturing and eating it. Students then posted their stories on Google Classroom so others could read through them, emulating the gallery experience students would have had in-person.

Typically, I introduce the evidence for anthropogenic climate change as we address the concept of scientific evidence in the nature of science unit, however we did not address climate change at all in the nature of science unit. I decided that to account for this I wanted to spend more time on climate change during the human impacts on the environment segment of the ecology unit. To achieve this goal, I had students complete a webquest about the history of the first earth day. In this webquest students had to collect information on environmental catastrophes in the middle of the 20th century, early whistleblowers like Rachel Carson and Paul Erlich, and early attempts at environmental legislation. Students then used the information they collected to construct a timeline of important events that lead to the development of Earth Day and the current status of environmental legislation.

Instructional Materials: Ecology Unit

As I prepared instructional materials for the ecology unit I knew that I would need to reduce the amount of time I expected students to pay attention during one sitting. I decided to give more frequent but shorter lectures during synchronous class time. I limited myself to 15-20 minutes windows at maximum. I also uploaded some shorter videos of myself explaining individual concepts for students that just needed to review one piece of instructional material.

Summary: Ecology Unit

During the course of my ecology unit adjustments were reached that better fostered student participation. Students were becoming more engaged with the material and completing more of their work on time. I was still seeking ways to present material to students that would encourage students to independently make connections between what they were learning in synchronous classes, the homework they were completing, and their summative assessment. I felt that there was still a lot of guidance required to help students understand the point of doing their online work before attempting the project.

Evolution Vignette

Introduction of Evolution Vignette

The second to last unit I teach in my biology class is an evolution unit. In this unit we discuss pre-Darwinian thoughts on evolution, Darwinian evolution and natural selection, and then modern perspectives on evolution. At the beginning of the unit we discuss Lamarckian thoughts on evolution and use what students learned about the scientific method in earlier units to make critiques of Lamarck's methods and shortfalls in his conclusions. We then delve into Darwin's work, closely examining the evidence that Darwin used to construct his theory of natural selection and the tenets of his theory. As we discuss Darwin we take time to make note of where his theory failed to adequately explain certain phenomena, and we incorporate knowledge learned from the genetics unit to address some of Darwin's shortcomings. As we incorporate genetics into our understanding of natural selection I encourage students to think of evolution as a change in the distribution of alleles in a population over time to fit a more modern syncretic approach to evolution.

Project: Evolution Unit

For the evolution unit I had students construct a comic strip that illustrates Darwin's theory of natural selection. Each comic was required to focus on one form of natural selection: stabilizing selection, disruptive selection, or directional selection. The example of natural selection used in the student comic needed to exhibit the chosen form of selection. Each comic was required to include the illustrations of following tenets of Darwin's theory: individuals of a species are not identical; traits are passed from generation to generation; more offspring are born than can survive; and only the survivors of the competition for resources will reproduce.

In an in-person environment I allow students to work independently or in pairs for this project. As students are working on designing their projects I will circulate through the room and ask students what organism they are focusing on, what special trait does their organism have that helps it survive in its environment, what type of selection they are showing, and where they illustrate different tenets of natural selection. Students are able to spend time discussing each step of the project with me and are able to make certain that every necessary element is present in their project.

In an online environment students had far less time to casually discuss their project with me in small groups as they designed it, so I decided that I needed to frontload many examples of how to complete this project before they started their design. Students had already become accustomed to the steps involved in PBL, so I felt confident that we could redirect focus away from learning how to complete a project. Instead, I wanted students to focus on creating an engaging high value product. When I first introduced the project, I provided each student with five samples of work, some being real student examples from previous years and others being work samples that I fabricated or found online. Each collection of work samples included one very high quality project, one very poor quality project, and three projects of intermediate

quality. I asked students to work in pairs to rank the comics from best to worst and assign a

number value to each project. I then asked students to explain why they ranked the comics as

they did, using specific examples from each comment of things they thought had been done well

or done poorly or were altogether missing. Students were then allowed to choose whether or not

they would continue to work in pairs on the project or if they would work independently. The

goal of having students rank these project samples was so that they would have material to draw

inspiration from and a better concept of things to emulate and things to avoid while designing

their own project.

The ecology unit had much higher rates of on-time project completion compared to the

nature of science unit. More students were able to complete their projects with minimal

supervision or one-on-one time with me or a para. Students were able to assess their own

projects as they designed them and turned in projects with fewer errors and with more of the

necessary components completed.

Homework Assignments: Ecology Unit

An assignment that I typically give to my in-person classes is a worksheet connected to a

Howard Hughes Medical Institute (HHMI) video on anole evolution. This video highlights

several different anole species, the environments they live in, and their niche within that

environment. The researchers in the video discuss specific characteristics that each species has

evolved to better fit into the niche it occupies. In an in-person environment I would have the

class watch the video together and I would pause the video after each species was discussed.

While the video was paused, I would ask students to discuss and recap the last segment we

watched, asking them what the anole's special adaptation was and how that helped it survive in

its environment. As we discussed each section students would answer a few reflection questions

per section. To take this assignment online I decided to have the students watch the video independently to save class time and because I believed the students had developed stronger motivation to complete assignments autonomously. When I assigned the video I gave students a document that recaps the main points from each section to emulate the class discussions students were missing out on. As students progressed through each section they answered the same reflection questions they would have if we had been in-person.

In order to prepare students for completing the project for the evolution unit I assigned two online assignments that were new to my classroom. The first assignment was a learning map graphic organizer differentiating the three types of selection. Students read three passages, each focusing on one type of selection, and had to create a bullet point list of important features and at least one real-world example of each type of selection from the reading. The second assignment was a webquest that covered the history of Darwin's voyage on the Beagle and used excerpts from his writing to explain how he arrived at the 5 principles of natural selection. Students had to navigate through the webquest and answer reflection questions testing their knowledge of Darwin's principles of natural selection and the evidence he used to derive those principles.

Students were given one final assignment for this unit, which was an assignment that I had used previously during in-person learning. This assignment required students to read a longer comic featuring an example of natural selection and then identify what type of selection was demonstrated and where different principles of Darwinian evolution had occurred in the comic. The major differences between delivering this assignment in-person and online were that students completed this assignment independently online and worked with a digital copy of the comic. Working with a digital copy of the assignment presented a challenge for special education students. During in-person learning I would allow students to mark-up the physical copy of the

comic that they were given. Many special education students worked with paras to highlight

specific examples from the comic rather than writing about the examples they saw in a separate

document. To help address this issue I gave special education students the option to verbally

explain the examples they saw in the comic in one-on-one Google Meets meetings instead of

turning in a document through Google Classroom.

Transitioning the homework assignments for my evolution unit to online was relatively

easier than it had been for previous units. Students had gained more confidence working in an

online model and had come to better understand what was expected of them. When choosing

homework assignments, I mostly chose material that would directly inform student projects,

however assignments were not literal steps in their project, in contrast to previous units like the

nature of science unit I had given assignments where students completed the steps of projects

directly through completing their homework. I expected students to use assignments to

familiarize themselves with concepts before attempting to apply those concepts to draw their

comic strip. This approach is more similar to a traditional classroom's use of formative

assessment, giving students the chance to work with concepts and increase their content

knowledge before applying that knowledge to complete a summative assessment.

Activities: Evolution Unit

An activity I use to illustrate the change in the alleles in a population is a lab activity

called "Breeding Bunnies." In this lab different beans are used to represent different alleles with

one allele conferring a disadvantageous trait. Each bunny is represented with a pair of beans to

symbolize the two alleles that give each bunny its phenotype. Students simulate the breeding of a

rabbit population to observe change in the ratios of alleles over time as the environment selects

for the most advantageous phenotype. Students record the changes in alleles and phenotypes and

answer reflection questions. Because I knew that students experienced difficulty working

through multi-step lab activities from home and I did not want students to fall behind, I decided

that for the online classroom we would conduct the breeding bunnies lab as one large group with

the teacher leading.

Another activity that I would typically have students do in-person is a simulation of the

evolution of rock pocket mice living in the Pinacate Peaks in northern Mexico. This assignment

is valuable because it requires students to synthesize what they have learned about genetics and

natural selection to make predictions about what will happen to rock pocket mice populations

living in different environments in the Pinacate Peaks. Most of the ground coverage in the

Pinacate Peaks is a light tan color due to the sand that forms most of the substrate there.

However there are also pockets of dark colored rock formed by lava flows that occurred in the

last 1,000 years. Students simulate the impact of a random mutation that causes some of the tan

colored mice to become black in populations that are living in the sandy tan-colored substrate

and populations living in the rocky dark-colored substrate. Students use different colored circles

of paper to represent the individual mice in the population and set them on either a tan colored or

black colored background. Another student then grabs the first ten colored circles of paper that

they see to simulate a predator consuming part of the population. After each round all surviving

mice produce one mouse that looks like them. Over several rounds the animals that have a coat

color most similar to the background color of the environment they live in tend to become more

common in the population. For most student groups the black mice will go from representing 5%

of the population to more than 50% of the population within 5 rounds and typically become

nearly 100% of the population within ten rounds. During online learning I did not think I could

conduct such a complicated lab procedure with students so I decided to instead have them watch

an HHMI video about rock pocket mouse evolution and then ask each student to imagine and

draw their own example of selection pressures caused by predation. I allowed students to either

draw a poster with an accompanying paragraph that explained what was occurring in their poster

or to draw a comic strip as practice for their final project. The online substitute for this activity

required students to exercise more imaginative thinking and engage in concepts they were

learning in a novel way by creating their own hypothetical example of evolution.

Instructional Materials: Evolution Unit

As I prepared the instructional materials for the evolution unit I used lessons I learned

from the delivery of instructional material in earlier units. I knew that I could not expect students

to always be in synchronous class. I also knew that students were not likely to spend much more

than ten to fifteen minutes meaningfully engaging with any instructional material I gave them.

For this unit I decided to split all of my lecture material into ten minute increments. Each lecture

focused on only one or two important concepts to mitigate the loss of learning due to

inattentiveness on the part of students. I recorded myself explaining each segment of the lecture

at least a day before I delivered it in class so I could have the video uploaded to Google

Classroom along with guided notes for each segment. Students would then be able to review any

part of the lecture they may have missed during synchronous class and those students who were

not able to attend class were still able to access the same material. By confining myself to a ten

minute time limit, I think I also made it more likely for students who missed class to be willing

to go into google classroom to review the material, rather than feeling daunted by a longer video.

Similarly to previous units students were provided with extra readings, videos, and online

simulations and encouraged to use these materials especially when they felt stuck.

Summary: Evolution Unit

Students were independently making connections between the work they did in homework assignments and the work they did for the project. They were beginning to take more agency in designing their projects and completing work independently. Students spent more time in class working on activities and their project and less time reviewing instructional material because they were more willing to go back and review instructional material independently in shorter increments.

Discussion

From the themes of successful online PBL came a set of instructional strategies for teachers to use to improve their practice as they transition to online PBL. These are strategies that can be incorporated into a teacher's toolkit to aid in the development of online PBL curricula, rather than an exhaustive list. See Table 3 for the eight instructional strategies generated from the themes.

These eight strategies are organized into three clusters of instructional strategies: project design strategies, chunking strategies, and modeling strategies. Project design strategies are intended to guide teachers as they consider the unique circumstances of online PBL. These strategies help anchor student voice and choice in a structured project design and allow teachers to provide greater scaffolding to students as they work on projects with greater levels of autonomy than either the teacher or student is accustomed to. Chunking strategies are intended to break up information into smaller pieces so that students can more easily digest complex information and avoid unnecessary frustration. These strategies provide students with the opportunity to complete projects in increments to eventually produce a well-informed and carefully designed product. Modeling strategies set expectations for students and give students

ideas to draw inspiration from. These strategies provide students with a frame of reference for behaviors they will have to engage in and the quality of work they produce while working on projects.

Table 3

Instructional Strategies for Online PBL

Instructional Strategies for Online PBL		
Instructional Strategy	**Cluster**	**Description of Instructional Strategy**
Independent Labs	Project Design	Develop a lab that can be conducted independently by students from home.
Alternative Projects	Project Design	Provide alternative projects so students can demonstrate mastery using multiple modes of learning.
Breakout Rooms	Project Design	Use breakout rooms and forum discussions for small-group collaboration.
Mini-Projects	Chunking	Assign mini-projects that require students to incrementally complete the work required for a larger project
Daily Checklist	Chunking	Provide a daily checklist for students to consult as they complete a project.

Breaking Projects into Steps	Chunking	Break group projects into discrete tasks so each member of a group has specific roles and tasks to complete.
modeling Products	modeling	Model how to construct the product for a project day-by-day by completing the same tasks that students are required to complete
Work Samples	modeling	Provide students with work samples and have them rank the work samples to guide them towards a higher quality project.

Project Design Strategies

The transition to online PBL created unique challenges for project design such as the inability to access appropriate materials, greater difficulty in facilitating communication between students, less contact time between students and teachers, less frequent check-ins on project progress, and the need for students to self-direct during work time.

Because we are aware that not all students have access to the same resources we need to bear that in mind when designing projects and driving questions. Online PBL educators should seek to create projects that students can work on independently from home. Leave out unnecessary demands upon students that do not meet learning goals and think about what materials and other resources the student will have available to them. Not all students have equal access to craft material,parental supervision or aid, or reliable internet. As teachers, it is our duty

to create opportunities for all of our students to demonstrate their learning through completing projects regardless of their socio-economic circumstances.

Students also have less frequent contact with their teachers during online learning and many students do not effectively use that contact time by seeking guidance. Because of the limited time teachers have to provide direct supervision and support for students working on projects it is of the utmost importance in an online environment to provide clear directions, preemptive answers to anticipated questions, research guides, and other supporting materials.

Students will invariably experience more self-directed learning during online learning and therefore PBL educators need to adapt project design for a more autonomous student. Because many students lacked the necessary skills to fully participate in self-directed learning it was important that projects were designed to facilitate the growth of independent learning skills and not punish students for having those deficits. For example, as students designed their projects they were asked to create rubrics and timelines to assess their own performance on projects. Students were provided with example rubrics, timelines, and finished products so that they could make their own determinations about how project design and execution results in a project's final product, and thereby make well informed self-evaluations.

Another important aspect in online project design is providing communication between the teacher and student through which they can discuss each project. In my classroom this took the form of a document shared with both the teacher and the student where students could record ideas about their project including their topic, design, what they intended to research, any data they had gathered, and other notes. A teacher can use this document to quickly check in on students and understand at which point in the process of completing a project a student is in.

Teachers can directly comment on areas where they see a need for improvement, can ask the student questions, and answer questions the student has for them.

Teachers conducting PBL online should provide flexibility and allow students to design their own projects or choose from several teacher-designed projects. One of the most common sentiments expressed by my students was that they did not understand what was expected of them and they did not feel confident meeting those expectations. Any opportunity where an educator can give students greater agency in their online education should be taken. Students that are given greater levels of voice and choice feel less ambiguity and greater levels of intrinsic motivation when working on projects. For students who feel overwhelmed by the prospect of designing their own projects, especially those students who are new to PBL, it is useful to provide them with teacher designed projects. It is important to offer some choice of selection for teacher-designed projects so that students can choose a project that is suited to their learning modalities and successfully express their mastery of concepts.

Teachers need to provide students with opportunities to complete individual projects and group projects. Students may feel hesitant about the prospect of group work at the beginning of their online education experience. Help students ease into working in groups through smaller formative assignments while they are working on larger projects independently. Independently completed projects are useful for having students exercise each of the steps involved in designing and carrying out a project. Individual projects give students an opportunity to exercise their critical-thinking and problem-solving skills while group projects help students practice communication skills and self-evaluation. Students engage in a variety of skills by practicing working both independently and in groups, helping them identify what approaches to PBL

facilitate their education. By combining a healthy mix of both types of project-work for students to complete, educators can give their students a well-rounded PBL experience.

Chunking Strategies

Chunking strategies gained a more prominent position in my classroom as I developed my online PBL practice. Some of the strategies that I employed that helped to both ease the burden on the students and myself were the implementation of mini-projects, describing discrete tasks for each group member in group projects, and providing daily checklists of tasks for students to reference as they complete projects.

One of the important chunking instructional strategies that emerged from this research is assigning mini-projects. With mini-projects students are able to digest information more thoroughly by completing smaller incremental steps towards a larger learning goal or project. By partitioning one larger project into several smaller projects students engage in product design more frequently, each individual project they create begins to feel less high-stakes and they become more comfortable with the process. Through growing more comfortable with the process of PBL and having a lower volume of material assigned at once students are more likely to complete their assigned work.

Another important chunking strategy is creating discrete tasks for group projects. When a teacher describes a project in terms of discrete tasks, group work tends to be divided more equitably. Giving the students a set of tasks to divide decreases the risk of one group member completing the entire project. This practice helps students engage in healthy communication skills, as they are held accountable to their group members and they check in on each other's progress on assigned tasks. When students are given a framework for dividing the work involved in completing a project into smaller steps, students are spending more of their energy engaging

with the material instead of determining the logistics of their work time. Creating discrete tasks makes it easier for a teacher to grade each student's contributions to a project.

Online PBL educators can provide outlines or daily checklists of all the tasks students need to complete for a project. With an outline in place students feel less frustration and lack of direction. An outline of tasks helps hold students accountable, it becomes more difficult for students to claim that they do not understand what they need to accomplish or cannot decide what to begin working on. Having a document that students can reference when they feel off-track makes it easier for teachers to spend synchronous class time giving meaningful instruction and feedback instead of answering questions about what students should be working on. In addition, teachers can spend less time redirecting off-task students by reminding them to consult their outline of daily tasks.

Modeling Strategies

For a successful online PBL experience educators should demonstrate how to complete specific tasks associated with each project. The ability to model individual steps in a project in real-time for students is limited during online education, so educators will need to come up with creative solutions for modeling tasks for students. Teachers can create videos modeling how to complete the steps of teacher-designed projects or spend time modeling during synchronous class periods. Students sometimes lose motivation due to confusion, which can prevent them from successfully completing a project. By showing students specific examples of how to complete each step within a project, educators can remove educational barriers and help jump-start the work process for students. modeling how to complete each task helps to remove that barrier to students attaining their education goals.

Many students struggle with time management, especially when faced with a large amount of work to do over an extended period of time. Educators should demonstrate how to divide all necessary tasks across the allotted work time to help students understand how much time they should spend on each task. Students tend to feel more motivated about completing a task once they have seen someone else successfully complete that task within the same timeframe.

Students are unsure of what constitutes a quality product. Online PBL educators should strive to provide a wide variety of product examples so students can familiarize themselves with what different high-quality products look like using different approaches to the same problems. When students are able to see examples of work of different qualities it gives them a better sense of how to construct a high-quality product. During in-person learning it is easier to informally show students examples, however during online learning the presentation of examples should be meticulously planned so that students can maximize the amount of time they have to work with and draw inspiration from each of the examples. Through careful preparation a teacher can ensure that students see a variety of examples including examples that utilize different approaches to similar problems and examples of varying quality.

Having students rank work samples is an excellent way to increase student investment in a project and anchor students' ideas about what constitutes a quality project. When students are able to rank a work sample and determine that it is sub-standard quality they are more cognizant of the potential pitfalls they may run into when constructing their own product and are better equipped to avoid making the same mistakes. Similarly, when students rank work samples as high quality, they are better able to identify what details in that product made it stand out as a

higher-quality product and then emulate that attention to detail when designing and constructing

their own products.

Overview of Changes in My Teaching Practice

At the beginning of the year my school's approach to online learning was mostly

asynchronous. Teachers were expected to post assignments for each day of the week and students

were expected to work on those assignments outside of class time. We saw that students were not

investing very much individual time working on their assignments, instead they were waiting

until class time to ask for help on the assignments. Because students were asking for more help, I

knew I had to change my approach and provide more scaffolding. I started reserving small

amounts of class time for touching on those asynchronous assignments that I was posting. I

would use this time to go through a few examples or ask if there are any particularly tough

questions that they wanted me to guide them through. I quickly learned that my students needed

a lot more guidance and they did not feel very motivated to work on these assignments on their

own so I switched my approach again and I decided that we needed to spend more class time

modeling how to work through these assignments. Although we did not have very much class

time to meet, I decided that it made more sense to model how to approach these kinds of

activities and work through them than to leave students in a greater state of confusion by

pressing ahead with more content. modeling served as a blend between assessment and direct

instruction. Some concepts were explained as they were encountered in assignments rather than

through lectures and other traditional forms of direct instruction.

One of the direct consequences of changing my approach to how I spent class time was

the significantly slower pace of the curriculum. Students were processing a big change in how

they received instruction and were not able to meet the same expectations that were established

during in-person learning. Students were struggling to process information that was taught

online. Students needed to learn how to complete assignments independently, how to use Google

Suite effectively, and how to ask for help when we were not meeting in person. Due to the fact

that classes were meeting less frequently I felt I had two options to address how I would deliver

the curriculum. One option was to frontload more curriculum online and expect students to read

and watch videos independently. The other option was to slow down and cover less breadth of

material in greater depth. I chose to slow down the pace of curriculum and take a deeper dive

into the material that we were covering instead of trying to maintain the breadth of material by

placing greater expectations on student participation external to class-time. Part of the rationale

for this decision was that students were already falling behind in terms of turning in classwork

and not coming to class prepared and well-versed in front-loaded material. I determined that

adding more material to the students' work load would not result in the outcomes I was hoping to

achieve. Finally, students had more questions than usual and were less reserved about asking

them. Every time that students had to complete an assignment outside of class I would receive

questions the next time we met, which was uncharacteristic for the students I served. I wanted to

capitalize on this teaching opportunity so I decided to emphasize the discussion of homework

during synchronous class periods. Students were asked to prepare their questions before class

time so that I could address specific inquiries about the material. After answering student

questions we spent time reviewing the assignment and highlighting the most important concepts

present in the assignment. Students recognized that we would be spending significant periods of

time discussing homework in class, which motivated them to complete class work ahead of time

and engage with the material in a more serious way. We covered less material because of the

spiraling nature of reviewing previous assignments, however students were taking more away

from each of those assignments and demonstrating mastery over the concepts we did cover.

My students were going through significant emotional distress due to factors like the

global pandemic, economic disruptions, and the murder of George Floyd. This meant I had to

exercise patience and flexibility in the online environment and remain open to dialoguing about

what was going on in their lives. Students regularly brought up these stressors and explained that

they were affecting their ability to fully participate in online learning. Students often requested

that directions were repeated to them several times. Although it can be a frustrating experience to

reiterate the same instructional material it is important to affirm students \by maintaining a

friendly and positive demeanor and addressing their needs such as repeating directions. Students

participated far more in my class after I repeatedly demonstrated patience and honored their

needs.

One of the greatest difficulties that my students faced was staying on track with the

intended pace of coursework. One of the strategies I implemented to circumvent this problem

was scheduling one-on-one or small group meetings with students outside of class to complete

work together. Students often failed to appear at these meetings and would regularly ask to

reschedule these meetings. Although again this can be a frustrating experience for the educator,

by exhibiting flexibility an educator can increase the buy-in from a student and uplift their

students during a difficult time. Because I continued to show flexibility and patience, students

dramatically improved their performance throughout the school year.

Online PBL educators can use components of projects in lieu of formative assessments to

help streamline project completion and mitigate the effects of slowing down the pace of

curriculum. Students encountered great difficulty balancing the time that they had to complete

formative assessments with the time they had to complete summative assessments. Many students fell behind in their formative assessments and then would spend too great of an amount of time trying to catch up on formative assessments while they should have been working on completing the more important summative assessments. To help prevent this problem from having a huge negative impact on students' grades, I decided to begin incorporating steps in a summative assessment as formative assessments in my classroom and I assigned less asynchronous homework not related to the project. Students were given entry documents which identified certain tasks associated with the project as an assignment that students would complete as homework before the final due date for the project. These assignments were then assigned one-by-one during the course of each unit and given the same attention that other formative assignments were, such as taking class time to answer questions and review. This approach helped students manage their time and it also helped complete tasks the correct way as they approached the completion of a larger project.

Another approach for online PBL educators to take is to allow students to focus more of their time and attention on producing quality projects and products. It will likely feel as if less material is being covered in an online format, however one way to respond to this problem is by allowing the focus to shift away from completing a high volume of work and shift into completing a small volume of very high-quality work. By having students focus almost entirely on completing projects they are able to focus on engaging in critical thinking skills and in-depth engagement with the material rather than trying to skim over a broader spectrum of material. If students are not immersed in their learning, they will not effectively retain information. The decision to reduce the volume of work allows students to more effectively engage with the

material and has the impact of students retaining a great deal of information related to the concepts they address in their project.

I used homework reviews as an opportunity to model how to engage with the material, instead of thinking of it as "correcting" homework. One of the impacts of this approach was that it reduced student stress. Students stopped thinking of homework as something they needed to do to avoid getting in trouble and started thinking of homework as something that they needed to engage with so that they could participate in class and understand the assigned project. Reviewing homework together as a whole class is an effective way to have students engage with the material, especially if teachers are concerned that students are not taking online formative assessments seriously or not reading feedback. Once students realized that I was not trying to find errors in their homework, but rather have them become familiar with the concepts related to their projects, students began to buy in more to completing daily assignments. Reviewing homework together as a class gave students who lacked confidence the opportunity to engage with the material appropriately and avoid making small mistakes that might damage their self-efficacy.

Implications for Educators

PBL is a unique approach to teaching that comes with a unique and ever-shifting set of challenges. Combining the unique challenges of PBL with the unique challenges of online learning presents a perfect storm of uncertainty and change that can leave educators struggling for answers. From this study emerges a toolkit of strategies that educators can incorporate into an online PBL teaching practice immediately to ease the transition to online PBL.

Another potential contribution of this study is to provide educators with encouragement in an unfamiliar setting. Some of the greatest adversities surrounding the transition to conducting

PBL online are the ambiguity and lack of precedent that educators may feel up against. When venturing into little explored territory in education it is easy to feel isolated and overwhelmed. Hopefully future educators that encounter this study will be able to use it as a source of precedent and help normalize their experiences.

A final contribution of this study is to provide educators with a launching point for future research. Each of the eight strategies presented in this study worked in my classroom, however their efficacy still needs to be tested formally. Data that could show that these strategies work or do not work in constructing a successful online PBL classroom would be beneficial to all online PBL educators.

Limitations

Some of the limitations associated with this environment are that I have a relatively small number of students, I have no collaborators, lack of quantitative data, student lack of familiarity with PBL, and convenience sampling. While my students may respond well to a certain strategy, given the tiny sample size these findings might not extrapolate well to other contexts. Due to the lack of other teachers in my department I had no collaborators to participate in the reflection on how successful strategies were with me, which lowers the validity of my observations. Due to my research design, I was not collecting quantitative data, because the focus of the research is on the teacher-learning process and finding ways for teachers to successfully adjust to teaching PBL online rather than specific learning outcomes for students. However, by not collecting and presenting quantitative data on specific learning outcomes for students the data is less empirically robust than it may otherwise have been. Many of the students in this class were previously unfamiliar with PBL, these students were faced with a double challenge of learning to adapt to PBL while also having to adapt to online learning at the same time. Rather than just

experiencing a shift in something they were familiar with to an unfamiliar environment these

students were being introduced to both new learning styles and new learning environments at the

same time. The study takes place in this specific school because this is where I taught, not

because this school is ideal for this study. A school better suited to this study may exist, however

this school was chosen for the sake of accessibility and familiarity.

Finally, my role in this school may influence my bias. As a researcher I attempted to

make objective observations about the effects of the strategies I implemented. My relationships

with the students and my desire to see them succeed may influence my perception of how

successful the students are. My familiarity and past experiences with PBL may influence my

perception of how successful PBL strategies are in general and in any specific instance within

the study. I did not have pay incentives or any other kind of compensation tied to the

performance of my students during this study, which helps to remove some bias that could be

created in this kind of environment.

Conclusion

During the course of the 2020-2021 school year schools across the nation abruptly

transitioned from in-person to online education. This swift change brought with it a host of

challenges for educators as they attempted to maintain the delivery of high quality education in a

new environment accompanied by unique and unforeseeable circumstances for educators and

students. The results of this study identified strategies that will allow educators to successfully

transition from delivering PBL in-person to delivering PBL in an online format.

Future educators seeking to employ these strategies in their classroom should consider

how they can begin to apply these strategies to their curriculum from the beginning of the school

year. In the context of this study these strategies were implemented into the classroom

one-by-one and slowly over the course of the year as collected data was interpreted and analyzed and action plans were developed to address problems that arose in the classroom. These strategies are likely to be more effective when students understand that these strategies will be implemented consistently throughout the school year and are aware of the supports that exist for them in an online PBL classroom.

Future research could seek to compare the relative efficacy of these strategies against one another. Research could also take the form of implementing various strategies at various points in the year and determine what is the most effective timing for the implementation of each strategy. I suspect that implementing all strategies from the beginning of the year would be most effective, but there is as of yet no research to support that claim.

In summary there are wide disparities in the conditions that exist in traditional in-person PBL learning environments and online PBL learning environments. These disparities need to be addressed with specific strategies, some of which overlap with strategies that are implemented within in-person PBL classrooms and some of which are unique to online classrooms. Online PBL classrooms will never be a perfect facsimile of in-person PBL classrooms. Instead of working to attain the closest approximation of in-person PBL, educators should instead strive to take advantage of the unique circumstances that exist within an online PBL environment and use online-specific strategies to target and compensate for deficits inherent in online education. Through the course of this study 8 such strategies have been identified for use by future online PBL educators.

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