ARES: AUTHENTIC RESEARCH EXPERIENCES IN SCIENCE
AN ASSESSMENT OF THEIR EFFECT ON HIGH SCHOOL STUDENTS' SELF EFFICACY AND PERCEPTIONS OF SCIENCE

Project Based Learning in Science Education

Project-based learning (PBL) is a teaching methodology in which students learn content and skills by engaging in real world problems and questions for an extended period and according to Larmer et al., (2015), can motivate students, prepare students for citizenship, help students meet standards, allow teachers to teach in a more satisfying way, and provide schools with new ways to communicate with communities. Over the last 20 years, many studies have supported these conclusions and have demonstrated that inquiry and authenticity, specifically delivered via PBL, positively influences students' information retention (Hume, 2009), engagement (Ahlfeldt, Mehta, & Sellnow, 2005). attitudes toward learning science (Sharma and Anderson, 2009), and desire to pursue STEM careers (Jollands, Jolly, & Molyneaux, 2012, Roberts and Wassersug, 2006).

However, while the value of implementing PBL is well documented, teachers have cited several issues which keep them from implementing PBL. One such limitation is that teachers often prefer teacher-centered instruction due to the perceived loss of control of other methods (Habók and Nagy, 2016). The perception is that when students work independently or collaboratively for extended periods of time student misconduct often increases, leading teachers to prefer more structured activities (MacMath, Sivia, & Britton, 2017). Interestingly, a recent large-scale international analysis conducted by Wang et al. (2022) lends support to these concerns. They found that among novice science learners, completely open-inquiry strategies were negatively associated with science literacy, while more structured-inquiry activities were positively associated with science literacy.

The ARES Framework

Here, we present a framework for the development of PBL units that gives teachers an adaptable, structured outline, while also including the "7 Essential Project Design Elements" (Larson et al., 2015).

The Authentic Research Experiences in Science (ARES) Framework (Figure 1) allows educators to develop guided-inquiry, PBL curricula reflecting their own research interests and technological capacity. While most PBL guides give a conceptual overview of what PBL units consist of, the ARES Framework provides a more concrete developmental structure and control over the student activities.

Background Content and Research Question Development
- Broad background of the problem is addressed
- Biological content necessary to understand the finer details
- Guided research question development as a class.

Methods Development and Data Collection
- Experimentation to optimize standard operating procedures
- Students given time to learn and optimize procedures before data collection takes place
- Multi-stage data collection

Analysis and Synthesis
- Data analyzed from subgroups and whole class
- Initial hypotheses are tested
- Knowledge development and synthesis

Figure 1: Generalized ARES Framework

Broadly, the framework mimics the structure and flow of a technical research paper. In the first phase, students are introduced to the background of the problem addressed and then guided to a clear research question. In the second phase, students are given time to experiment with techniques and procedures to develop the standard operating procedures they will later use to collect data. Importantly, students are specifically taught the scientific nuances of the procedures and given multiple opportunities to try and retry them until they feel comfortable. Once comfortable with the procedures, students are given a specific subset of samples to collect data from, and a substantial amount of time to do it. In the final phase, students analyze their own and the class's data to make conclusions to generate new knowledge.

Many undergraduate professors employ a similar framework in the development of Course Based Undergraduate Research Experiences (CUREs) (Bakshi, Patrick and Wischusen, 2016). Nationwide, CUREs are becoming widespread in community and 4-year colleges, and research has shown that CUREs can improve self-efficacy (Martin et al., 2021) and understanding of the Nature of Science (Linn et al., 2015). However, this model has not been as rigorously tested in high schools.

The goal of this study is to evaluate a project-based curriculum developed using the ARES Framework to determine if its' effect on high school students' self-efficacy and perceptions of biology is consistent with previous data collected on PBL and CUREs. Due to the action research methods employed here, we chose to focus our data collection on self-efficacy and career perceptions because these two psychological constructs are most associated with long-term persistence in careers (Bandura, et al., 2001; Lent, Brown, & Larkin, 1984; Wigfield and Eccles, 2000).

Study Design

Study Setting and Participants

This action research study was conducted in the Spring of 2021 in a high school biotechnology course. Students in this course chose to take it as an elective CTE class and were concurrently enrolled in a core science class. A total of 40 students (21 female, 19 male; 33 sophomores, 6 juniors and 1 senior) participated in the ARES aligned curriculum and were surveyed before and after the project took place. Of the 40 students who participated in the curriculum, only 26 students consented to use their survey data.

Curriculum Design

Using the ARES framework, instructors developed a semester long PBL curriculum in which students investigated the microbiome of local mosquitoes using an Oxford Nanopore minION sequencer. In the first phase, students learned about the impact of mosquitoes on contemporary and historic human societies and the dynamics the microbiome can play in pathogen competency. In the second phase, students optimized DNA extraction and quantification procedures for individual adult and larval mosquitoes and practiced evaluating nanopore sequencing data. We then completed nanopore sequencing of 12 locally caught mosquitoes and spent time analyzing the ~12GB data set. In the final phase, students engaged in data analysis asking sub-questions within our main research objective. Each student developed a question about the microbiome of our mosquitoes and answered it using the available data.

Surveys

Two research tested surveys were administered before and after the project took place. The first survey was a 24-item self-efficacy survey designed and validated by Baldwin, Ebert-May, and Burns (1999) to test the effectiveness of teaching and learning strategies in biology. Respondents rate their response on a 5-point Likert scale, and questions are grouped into three categories reflecting confidence in: 1) Methods of Biology, 2) Generalization to Other Science Courses and Analyzing Data and 3) Application of Biological Concepts. Normalized change (Marx and Cummings, 2007) from pre to post curriculum delivery was calculated for each question and changes in each of the three categories was calculated by taking the mean normalized change of each question in that category.

The second survey administered was a 31-item Science Perception Survey developed by Semsar et al., (2017). The Colorado Learning Attitudes about Science Survey (CLASS-BIO) is a valid and reliable survey used to evaluate whether a particular pedagogical technique can help develop an "expert-like appreciation of the nature of biology". Student responses were scored using the CLASS-BIO Scoring tool, and their responses were categorized as either favorable (in-line with expert responses) or unfavorable (out of line with expert responses).

Analyses and Findings

Self-efficacy Results

Of the 26 students surveyed, 25 completed the entire survey. The average normalized change for each of the three categories of student confidence grew from the pre-survey to the post-survey. Student growth was highest in the Methods of Biology (17.63%), and Generalization to Other Science Courses and Analyzing Data (13.44%). The individual questions that had the most significant change from the pre to post had to do with experimental design and synthesis of experimental work (Figure 2).

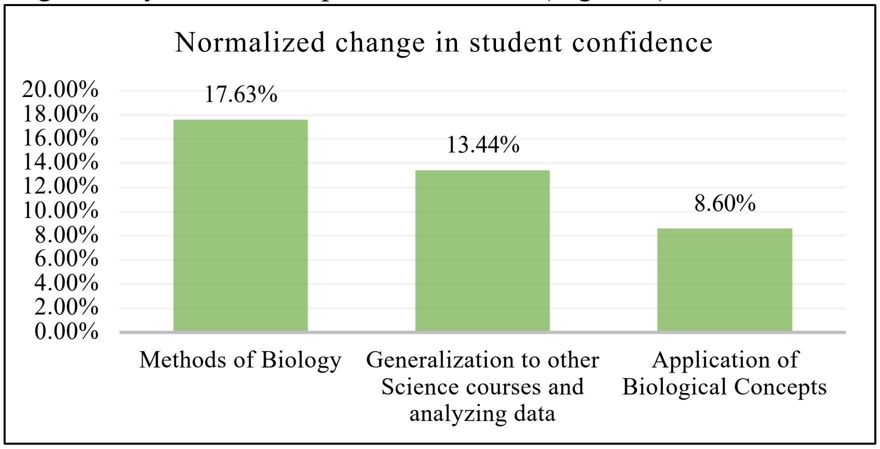

Figure 2: Normalized change in student confidence from pre-post survey data. (N=25) Normalized change percentages indicate a % change on a 5-point Likert scale. i.e. 20% change = 1 point difference on a Likert scale.

CLASS-Bio Attitudes Towards Science Results

The CLASS-BIO contains one item that is used to assess valid completion of the survey, and based on the data from this question, 6 students' surveys were discarded from the final analysis. 20 Students successfully completed the CLASS-BIO, and the results were analyzed by looking at

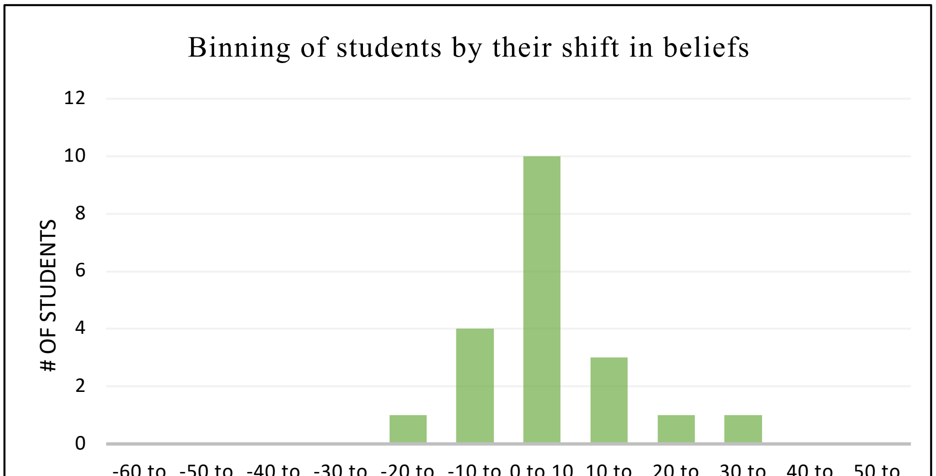

Figure 3: Shift in expert-like appreciation of the nature of biology as measured by CLASS-BIO survey. (N=20)

the percent of responses which were seen as favorable, or more in line with expert responses.

On average, 15 of the 20 students shifted favorably in 0-20% of their responses and two of them shifted favorably in more than 20% of their responses. 5 students shifted unfavorably in 0-20% of responses (Figure 3).

Conclusions

Coming back from nearly a year of virtual learning was a difficult transition for everyone. When we designed this curriculum, we set out to address something that was interesting and applicable to students' life. We wanted to keep the content accessible, while also asking them to perform lab techniques and analysis to a professional standard.

Overall, students that participated in the Mosquito Microbiome project developed a more expert-like understanding of how problems can be solved in biology as measured by the CLASS-BIO survey. They also became confident in the methods employed by biologists to ask questions, design experiments, and write a synthesis of their work as measured by the 24-item self-efficacy survey. While directly attributing these gains to the structure of the curriculum itself may not be possible without a larger sample size and a control group, it is nonetheless an encouraging pilot. Future studies will look at a more widespread application of ARES projects across several different ages of students and apply a retrospective cohort model to assess persistence in STEM compared to traditional teaching methods.

Contribution

The main contribution of this work is the ARES Framework itself, which can help K-12 teachers develop a structured approach to delivering authentic research projects. As K-12 school districts around the country adopt NGSS-aligned assessments, PBL in science is becoming the preferred method to blend the three dimensions of science learning. NGSS Storylines can provide an "off the shelf" curriculum resource, but many educators may prefer tailoring their curriculum to better suit the interests and needs of their community. The ARES Framework can be applied to help design these types of tailored, PBL experiences.

General Interest

One of the most interesting components of this curriculum that has not yet been discussed is the application of the Oxford Nanopore minION Next Generation Sequencer in a classroom. Many high school biotechnology courses already have most of the technological infrastructure necessary to start conducting their own next generation sequencing projects. The minION sequencer is affordable, easy to use, and can produce rich datasets for bioinformatic analysis. Even for schools that lack the necessary technology, ARES Projects about metagenomics can still be created using open-source data sets and bioinformatic tools.

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