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Black Rhino
(*Diceros bicornis*)

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Kreuger National Park, South Africa

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65th ANNUAL MEETING

ACUBE is optimistically planning for an in-person meeting at the University of Portland in Portland, OR on October 14-15, 2021.

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Articles

The Zoom Map: A New Graphic Organizer to Guide Students' Explanations Across the Levels of Biological Organization

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Abstract

Employing scientific reasoning when giving biological explanations comes easily to the experienced scientist. However, students often encounter difficulty when they attempt to explain biological phenomena. One significant obstacle appears to be the failure or inability to bear in mind the levels of organization. To address this issue, learning strategies, such as the yo-yo learning and teaching strategy, recommend moving across the levels of organization and making those levels explicit in the explanation. To support yo-yo learning, we developed a new graphic organizer, the zoom map. The zoom map combines the levels of organization with concept maps. It is specifically tailored to guide students in biology on ways to distinguish, interrelate and reflect the levels of organization. In this paper, we introduce the zoom map as a tool for instruction and diagnosis. We also provide evidence from teaching experiments that demonstrate how the zoom map benefited learning.

Keywords*:* graphic organizer, concept map, levels of organization, yo-yo learning, systems thinking

Introduction

Employing scientific reasoning when giving biological explanations comes easily to the experienced scientist. However, students often struggle to explain biological phenomena. One significant obstacle is the failure or inability to bear in mind the levels of organization. Research conducted on a wide range of topics has revealed that the levels of organization often present an obstacle to learning in biology (Schneeweiß & Gropengießer, 2019). Confusing the levels (Wilensky & Resnick, 1999), explaining on only one level (Jördens et al., 2016), or failing to interrelate the levels (Brown & Schwartz, 2009) are often at the root of the problem.

To assist teachers, Jördens et al. (2016), and based on previous work by Knippels (2002); Knippels et al. (2005); Verhoeff et al. (2008) adapted the yo-yo learning and teaching strategy. Moving up and down the levels of organization is the underlying principle of yo-yo learning, and this technique has been valuable for structuring learning sequences and guiding teaching processes. Nevertheless, teachers still need to explicitly encourage learners to interact with the levels of organization (Hammann, 2019).

To remedy this shortcoming, we have developed a new graphic organizer, the zoom map. This is a tailor-made tool to guide biology students and help them distinguish, interrelate, and reflect the levels of organization. In the section below, we first explain our understanding of how explanations are constructed. We then describe the starting points for the development of the zoom map, namely the concept map and yo-yo learning. Finally, using case studies taken from our teaching experiments, we explain and discuss the learning opportunities and difficulties presented by the use of the zoom map.

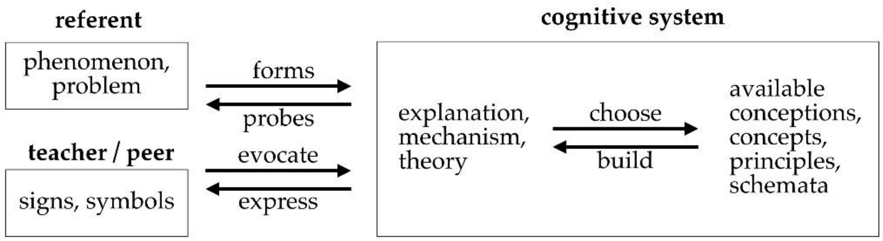
Theoretical Background

2.1 Emergent construction in interaction

Students do not have existing explanations for phenomena already stored in their memory. Instead, students construct such explanations in situations of social learning and through interaction with three sources, two of which are external and one of which is internal. To construct an explanation, an individual interacts with (1) the object of reference (i.e., the

Figure 1.

Emergent construction in interaction.



Emergent construction in interaction (arrows) with a phenomenon, utterances of teacher or peer, and the resources of available cognitive structures.

phenomenon to be explained) (2) other people (i.e., teacher and peers) and (3) with their available cognitive resources (i.e., conceptions, concepts, principles, and schemas) (Figure 1). This process is called "emergent construction in interaction" (Boersma & Geraedts, 2009; Schwarz et al., 2008).

The construction process needs time and may involve trial and error. The result is a temporarily conscious but ephemeral explanation that rests on available stable cognitive structures.

Emergent construction in interaction results in explanations, mechanisms, and theories that usually constitute relatively complex structures. For instance, explanations do not stand alone. From a scientific standpoint, explanations should be interrelated with other kinds of knowledge. The interrelatedness of knowledge is therefore crucial to the quality of explanations (Linn et al., 2006).

2.2 Graphic organizers for knowledge interrelation

Graphic organizers (GOs) are tools that aid students with knowledge interrelation and have proved fruitful in the teaching of science and biology (Davidowitz & Rollnick, 2001). GOs are "visual knowledge representations" (Nesbit & Adesope, 2006) that can be used to "organize and structure information and concepts and promote thinking about relationships between concepts" (Zollman, 2015, p. 4). Concept maps (CMs) are a well-known example (Novak & Cañas, 2006).

GOs can be constructed by both the expert and the student. On the one hand, expert generated GOs may be beneficial for students because such GOs offer a coherent representation of expert knowledge (Robinson & Kiewra, 1995), and they focus on the interrelation of concepts (Hall et al., 1999). On the other hand, recent findings show that GOs constructed by students themselves improved their comprehension skills (National Reading Panel, 2000) and led to the generation of more interrelated ideas (Schwendimann & Linn, 2016).

2.3 Understanding is based on experience

If we assume that GOs help students to structure and interrelate existing knowledge and that knowledge is actively built by the students based on their prior knowledge (von Glaserfeld, 1989), we must ask two crucial questions: How does basic available knowledge emerge in an individual, and how can students acquire new conceptions?

The theory of experientialism (Gropengießer, 2007; Lakoff & Johnson, 1999) suggests an answer: Cognition is embodied. Our basic concepts, principles, and schemata arise from recurrent interactions with the physical and social environment, through perception and experience. Physical experiences induce embodied concepts and schemes that can be understood directly, such as "tree" or "source-path-goal schema" (Niebert et al., 2012). Abstract concepts, such as scientific explanations, mechanisms, and theories, are not understood directly but by imaginative thinking. This process can be described as "understanding through conceptual metaphors" (Gropengießer, 2007; Lakoff & Johnson, 1999). Conceptual metaphors bridge "the gap between experience and abstract phenomena" (Niebert et al., 2012, p. 852).

Teachers should offer opportunities and environments that foster meaningful learning (Ausubel, 1968). To make learning meaningful, interventions should, on the one hand, connect to prior knowledge and, on the other hand, adequately guide the interaction process (Novak & Gowin, 1984) We propose the zoom map as a tool that would help teacher achieve both these goals..

The Zoom Map - A Graphic Organizer to Guide Explanations

The zoom map is based on findings taken from three areas: GOs (particularly CMs,) yo-yo learning, and research on the structure of levels of organization.

3.1 Concept maps

According to Novak and Cañas (2006), a CM can be characterized as follows (Figure 2):

1. A term for one concept is displayed in a box.
2. Lines may connect the boxes, with linking words or phrases (Javonillo & Martin-Dunlop, 2019) in such a way that the terms and linking words can be read as a meaningful statement.
3. The CM is arranged hierarchically: More general concepts should be placed near the top, while more specific concepts should be placed near the bottom.

Based on the theoretical background provided here, we regard the CM as an external representation that expresses the concepts or internal representations of the cognitive system. Terms in a CM denote concepts, statements denote principles, and notions and labels denote relationships.

CMs support meaningful learning by fostering a) externalization (verbalizing and writing concepts as external representations), b) interrelation and c) (re)organization of knowledge (i.e., concepts and prepositions) (Dauer et al., 2013; Fischer et al., 2002; Novak & Gowin, 1984).

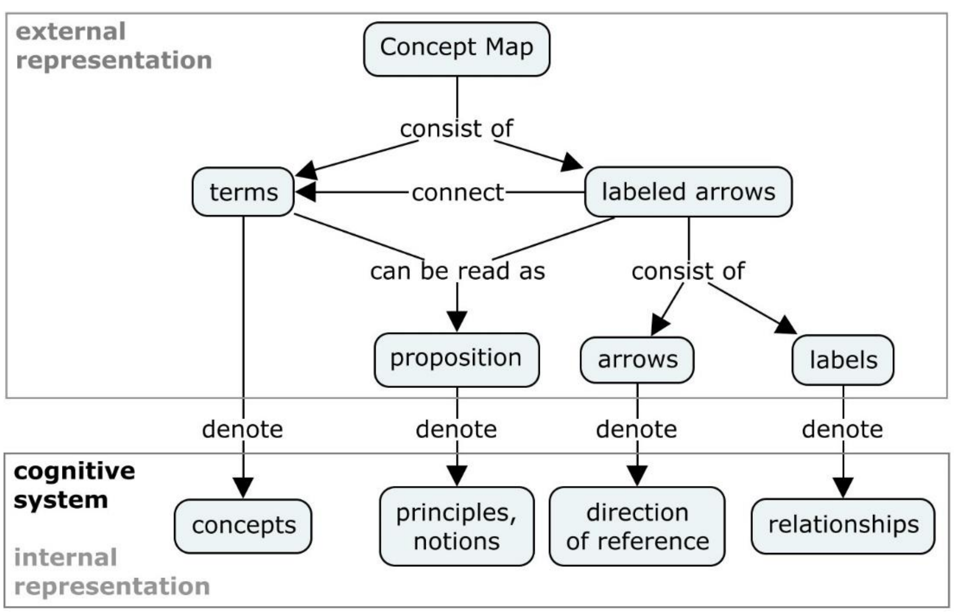
According to Schwartz and Brown (2013), GOs, and especially CMs, can help students connect system levels. The importance of making levels of organization and their relationships explicit was a key insight that we drew from our previous work (Schneeweiß & Gropengießer, 2019). However, existing approaches that used CMs in the context of systems thinking (Brandstädter et al., 2012; Dauer et al., 2013; Schwendimann & Linn, 2016) did not make levels of organization and their relationships explicit.

3.2 Supporting systems thinking with yo-yo learning

The yo-yo strategy builds on the idea of moving up and down the levels of organization – like a yo-yo. The goal of this strategy is to interrelate concepts at the same level (horizontal coherence) and between different levels (vertical coherence) (Hammann, 2019; Jördens et al., 2016; Knippels, 2002).

Figure 2.

Self-referential concept map.



Self-referential concept map (CM) showing its key features.

Our GO, the zoom map, incorporates and supports the steps for teaching systems thinking adapted from Jördens et al. (2016, p. 961). We present the steps with a small deviation. We added an additional step (step 2) in order to identify the components and processes (Tripto et al., 2016, p. 82) before interrelating them. We hypothesize that this will make it easier for students to:

1. Distinguish different levels of organization;
2. Identify the components and processes of a system (and relate them to a level);
3. Interrelate concepts at the same level of organization (horizontal coherence);
4. Interrelate concepts at different levels of organization (vertical coherence);
5. Think back and forth between levels (also called "yo-yo learning")
6. Meta-reflect on the question of which levels have been transected.

3.3 Zooming: A metaphor for levels of organization

An abstract concept such as the levels of organization cannot be understood directly. To develop our GO, we needed a metaphor for the levels of organization. Although the term "levels of organization" is commonly used in biology, there is no scientific consensus on its description. However, there is consensus about what the levels can do: They can structure scientific problems (Brooks, 2019; Schneeweiß & Gropengießer, 2019). As proposed by Schneeweiß and Gropengießer (2019), based on a critical literature review, zooming is a metaphor for the levels of organization. By zooming in, one focuses on increasingly smaller sections of the problem space without losing sight of the context (Brooks, 2019). By zooming out, one takes the whole, or the context, into account. The metaphor of zooming therefore introduces the notion of structuring scientific problems by focusing on different levels.

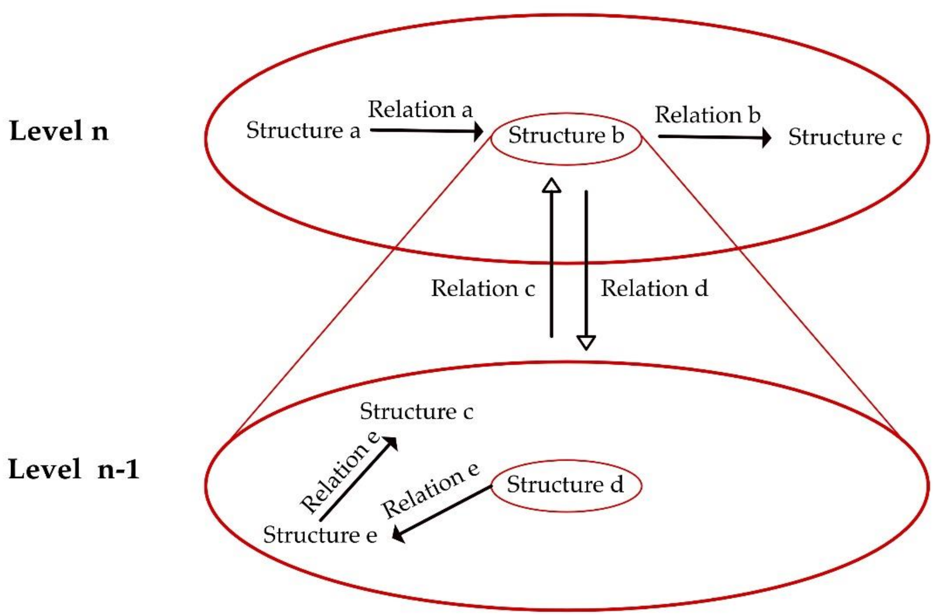
Through zooming, we can structure the biological system as consecutive levels of organization, or "zoom levels." The levels are established and connected by different relationships (physiological, coevolutionary, phylogenetical, and matter-energy relationships) that can interrelate the system parts. Depending on the biological phenomenon or research problem being studied, an explanation may require different levels of organization (Schneeweiß & Gropengießer, 2019).

3.4 How to construct a zoom map

We used the metaphor of zooming in and out and combined it with a CM to create a new type of GO, the zoom map (Figure 3).

Figure 3.

Model of a zoom map.



The basic rules for drawing a zoom map were adapted from those that apply to concept mapping (Novak & Cañas, 2006):

1. The levels of organization are displayed as ellipse shapes (Eronen, 2015). By zooming in on a structure at one level, one reaches a lower level. By zooming out, one reaches a higher level.
2. Each ellipse contains the terms for particular concepts.
3. Lines may connect the terms or the levels with linking words. When read together, the linking words and terms should make sense.

The layout of the zoom map can be adapted to the phenomenon that is being taught. However, the explanation that is being sought must involve specific levels of organization. For example, explaining physiological phenomena will require the level of organism and below, while explaining evolutionary phenomena will require the levels above the organism as well, such as the level of population (Schneeweiß & Gropengießer, 2019). In addition, two zoom maps can be juxtaposed. This will be useful when comparing structures and processes in two different organisms, for example.

We will demonstrate and discuss the implementation of zoom maps in the next section.

Our Application of the Zoom Map in Teaching Experiments

4.1 Method

To investigate the potential of the zoom map, we conducted six teaching experiments (A-F). In this variant of a Piagetian interview, the interviewer has two roles: interviewer and teacher (Komorek & Duit, 2007; Steffe & Thompson, 2000). In the first part of the teaching experiment (diagnosis), all the students were interviewed so the interviewer could evaluate how much knowledge the students already had. In the second part (teaching), students were provided with learning material (see 4.2). They worked in dyads in a laboratory setting. Throughout the experiment, students were encouraged to work together and to express their thoughts. No content-related guidance was offered by the interviewer. The focus of the experiments was on the learning opportunities and difficulties that arose from using the zoom map.

Twelve high-school students, with an average age of 16.2 years, participated. All the students and their parents gave informed consent. The interviews were recorded in audio and video and transcribed afterward. We analyzed the transcripts by means of a computer-supported qualitative content analysis (Kuckartz, 2010).

4.2 Material

M1: Two photographs of a variegated nettle, one well-watered and one wilted

M2: A semi-structured zoom map (Figure 5)

M3: Material showing the phenomenon on consecutive zoom levels (photographs)

M4: Material showing the phenomenon on different zoom levels (graphically)

M5: Two models, one with under-inflated and one with fully inflated balloons in connected nets, modelling cells at the level of tissue.

4.3 Schedule of the teaching experiment (Figure 4)

We presented two photographs of a variegated nettle (*Solenostemon scutellarioides*). One photograph shows the plant in a well-watered state, with turgescent, stiff, and erect leaves. The other photograph shows a nettle with wilted and sagging leaves. The students were asked to explain the structural differences between the two states.

Figure 4.

Schedule of the teaching experiment.

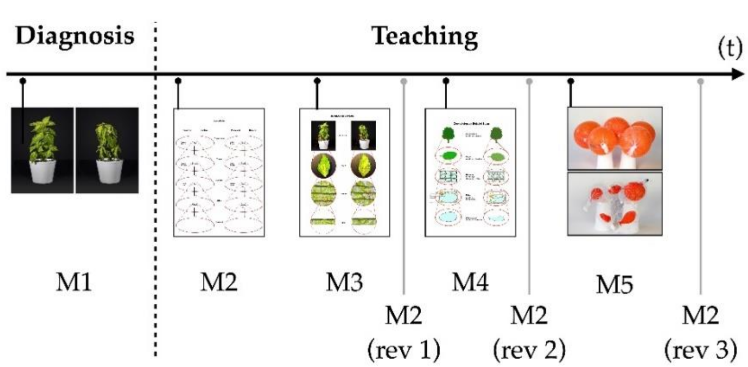
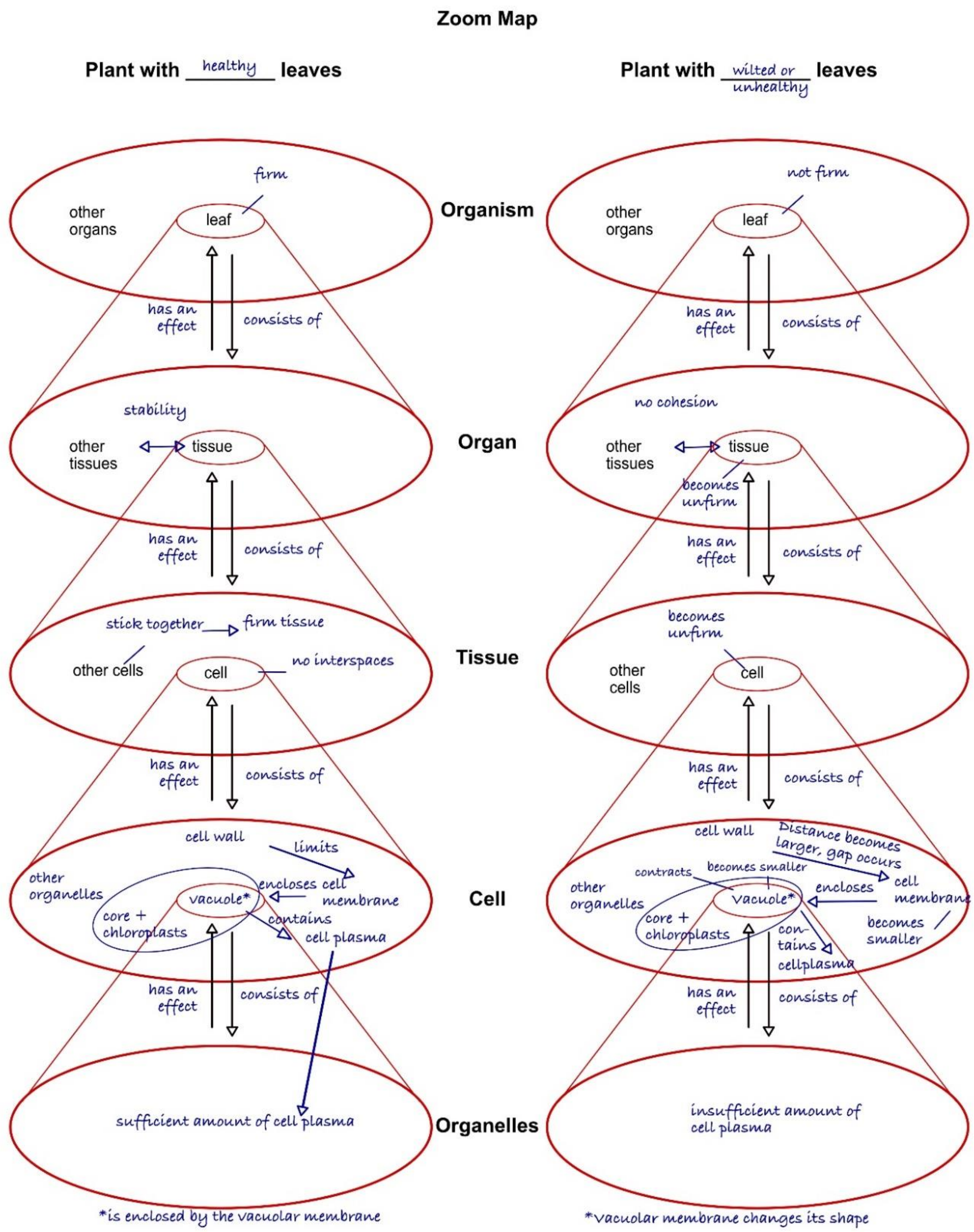


Figure 5.

Examples of student-constructed zoom maps.



Examples of student-constructed zoom maps explaining the difference between a plant with healthy leaves and a plant with wilted leaves. The students' answers are shown in handwriting (teaching experiment C, translated from German to English).

1. Students are asked to describe and explain the phenomenon (M1).
2. Students are asked to use the zoom map (M2) to represent their explanation.
3. Students are asked to describe M3 and revise their zoom map accordingly (rev 1).
4. Students are asked to describe M4 and revise their zoom map accordingly (rev 2).
5. Students are asked to describe and use the models (M5) and revise their zoom map for the final time (rev 3).
6. Students are asked to explain the phenomenon based on their final zoom map.

Results

As educators we are interested in the learning opportunities offered by the zoom map and the difficulties students face when working with this graphic organizer (Figure 5). We are also interested in how students experience the use of this strategy to explain phenomena.

5.1 Learning opportunities

First, although the learning strategies of zoom maps and CMs were new to them, the students were able to construct a zoom map that displayed their understanding of the phenomenon (Figure 5). In their interaction with the zoom map, students (S):

a) identified structures and related them to levels:

Students were able to relate relevant components of the system (plant) to the corresponding level of organization. For example, relations were drawn between the cell wall or cell membrane and the level of the cell (Table 1). Linking system components and linking those components to the levels of organization is one of the first steps in systems thinking.

b) interrelated levels horizontally and vertically (Figure 5):

Based on their own zoom maps, students were able to interrelate structures horizontally and vertically. Horizontal interrelation is the interrelation of notions on the same level of organization, for example, the notion "cell wall —limits—> cell membrane" (Figure 5). An example of the vertical interrelation is the notion "organism —consists of—> organs."

c) reflected on and discussed the assignment of structures to levels:

S1: Yes, exactly, but you know, we can also make an arrow like that here, [...] because <u>this [vacuole] belongs to the cell</u>, right?"

S2: Yes (teaching experiment E, line 92-93) (Similar in teaching experiment A, line 65-70).

d) Students reflected and discussed horizontal and vertical coherence:

S1: <u>Actually, you could do the arrow the other way around</u>, because the organelle, so to speak, took care of it (teaching experiment D, line 152).

S2: So, what are you writing now?

S1: Internal cell pressure is high or something, and for you it is just small.

Table 1.

Syst*em components that students related to the levels of tissue, cell and organelle in their zoom maps (translated from German.*

Teaching Experiment						
Level						
	A	**B**	**C**	**D**	**E**	**F**
Tissue						Cells
Cell	Cell wall Cell membrane	Cell wall Cell membrane Vacuole Cell plasma	Cell wall Cell membrane Vacuole Cell plasma Chloroplasts core	Cell membrane Vacuole Cell plasma Chloroplasts core	Cell membrane	Cell wall Cell membrane Vacuole Cell plasma Chloroplasts core
Organelle	Liquid	Water	Cell plasma	Water	Cell membrane Vacuole	water

S2: Yeah, okay.

S1: <u>And that has an effect on the tissue, right?</u>

S2: Yes (teaching experiment E, line 95-99)
(Similar in teaching experiment F, line 149-152)

5.2 Students' perception of the zoom map

The students understood the benefit of the zoom map:

S2: Yes, to be able to understand a phenomenon much better […] by proceeding in much smaller steps. You simply write down your thoughts and what you see and then simply continue working.

S1: […] You create things for yourself. In school you learn how things are and now S2 and I have explained this to ourselves in small steps. That's not always the case at school. Normally, we just know that something exists or is dependent on it, but not exactly why. And now we actually know quite well that really every smallest molecule (/)

S2: (/) has an impact on something bigger (teaching experiment D, line 332-333).

5.3 Learning difficulties

Despite the benefits of the zoom map, students struggled with it at first. One challenge was the assignment of structures to the levels.

S1: If you don't have much to do with biology anyway. (/) So, we first had to clarify what a vacuole is. You could already see from the arrows that something is dependent on each other or has an effect on each other. But if you don't know what a cell is made of, or a vacuole, then you don't have an idea (teaching experiment D, line 284).

Moreover, some students did not follow the rules for the construction of a zoom map. Their maps partly resembled mind maps and terms remained unconnected (Figure 6)

Discussion

Biology students struggle with the levels of organization. One of the ways in which teachers can deal with this issue is to use the principles of yo-yo learning. The explicit reflection of and reference to the levels of organization is a defining characteristic of yo-yo learning. We propose the zoom map as a new graphic organizer to guide students across the levels of organization. The zoom map supports the construction of explanations according to the principles of yo-yo learning in the following ways:

By distinguishing different levels of organization

The zoom map depicts the various levels as wide, stacked ellipse shapes. Figure 5 illustrates the levels from organism to cell organelle (In the case of other phenomena, different levels would be depicted).

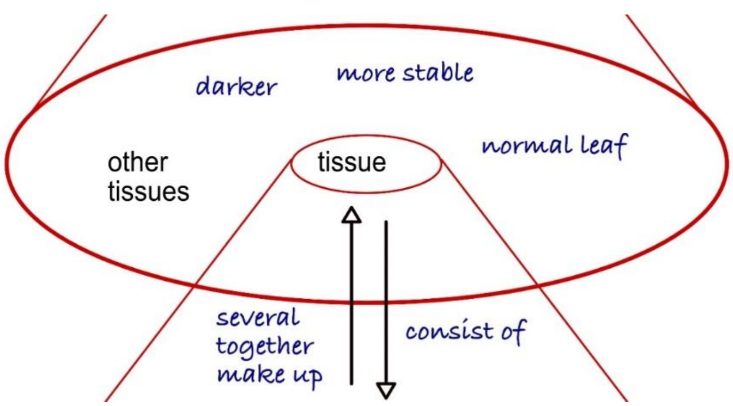
1. By identifying the components and processes of a system (and relating them to a level)

System elements can be assigned to a system level by writing them into the ellipse shapes. In Figure 5, the cell membrane and the cell wall are assigned to the level of cell.

.

Figure 6.

Zoom map of students form teaching experiment B.



Students of teaching experiment B did not interrelate terms in their zoom map (The students' answers are shown as handwriting).

2. By linking concepts that are at the same level of organization (horizontal coherence)

The system elements are linked by words or phrases that form propositions when the reading direction indicated by the arrows is followed. The rules for the construction of CMs apply. Propositions should be meaningful.

3. By linking concepts at different levels of organization (vertical coherence)

The user of the zoom map can zoom in on each structure and then describe the system at a lower level (n – 1), for instance, when zooming from the level of tissue to that of cell. On the level of the cell, the user can again assign and link system elements. The different levels can be related vertically.

4. By thinking back and forth between levels (yo-yo learning)

When trying to explain a phenomenon, students should start at the level of that phenomenon. Usually, this is a level that is within the range of perception, like the level of organ, organism, or population. With the help of supporting material, students can move downwards and explore each level, repeating steps 1 to 4. Finally, based on their zoom map, they can try to give causal explanations of the phenomenon or identify missing knowledge. This step usually involves moving upwards in the zoom map.

5. By allowing for meta-reflection on the question "which levels have been transected?"

Moving across levels and reflecting those levels are inherent to the construction of a zoom map. The first indication of a level occurs when system elements are assigned to levels. The second indication of a level concerns the horizontal and vertical interrelations. In the construction process, students have to make choices. Comparing individual zoom maps can further support learning. The teacher should give feedback and guide the discussion as needed.

Some of the students who participated in our teaching experiments struggled to work with the zoom map. This might be due to their lack of experience with the levels of organization, especially levels lower than "organ." This does not mean that these students will not be able to learn using this method. Teachers or peers can encourage struggling students to reconsider unrelated terms. If the student can make no further connection, missing interrelations may indicate subject areas that the student has not mastered yet.

It is important to note that the zoom map can only support the construction of ideas and notions on a phenomenon. To enable the construction of adequate concepts, students need additional material (e.g., photographs, experiments) that offer the necessary experience of the phenomenon and to further denote conceptions (Niebert et al., 2012). Even in a zoom map, students will not be able to link concepts that they have not yet constructed in their minds. Depending on the needs of the students, different levels of scaffolding are possible.

The expert zoom map is the simplest form. Constructed by the teacher, the map guides the students during instruction or serves as a comparison with a student-constructed zoom map. Semi-structured maps are an accessible introduction to zoom maps (Figure 5). Students are asked to complete zoom maps that have been partly filled out. The semi-structured map supports the construction process by making it easier to relate structures to the levels of organization.

Students who are familiar with the principles of the zoom map can work with empty maps that depict the levels only. Eventually, advanced students can construct their own zoom maps by deciding which levels are needed to explain the phenomenon in question.

Like CMs, zoom maps can be used as a diagnostic tool. A completed zoom map expresses a student's conceptual framework across the levels of organization. The zoom map will reveal not only the learning gains that have been made but also any remaining issues related to levels of organization, for example, when interrelations are missing or there is slippage between levels.

Conclusion

The zoom map can be a valuable tool in the teaching and learning of biology. When students interact with a zoom map, its inherent structure allows them to construct explanations that span multiple levels. The zoom map therefore guides students across the levels of biological organization and offers starting points for horizontal and vertical coherence. Like CMs, the zoom map is a learning strategy – as such, it has to be learned (Sumfleth et al., 2010). It is therefore advisable to support students by offering different scaffolds, such as semi-constructed zoom maps or expert maps, until they understand the principles involved.

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Virtual Labstore: A Tool to Facilitate Inquiry-based Laboratory Research Education

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Abstract

In our biomedical educational program, students follow research courses. Traditionally, students receive research questions and pre-determined, teacher-prepared lists of laboratory materials to use. Currently, we aim to increase our research courses' inquiry level towards a more open inquiry by omitting these teacher-prepared lists. Additionally, we want to enhance the flexibility of student-teacher interactions during research courses. Therefore, Virtual Labstore was developed. This is an online 3D laboratory stockroom in which students are able to browse all the laboratory materials present in our university and buy materials for their experiments within the limits of pre-determined financial budgets. Furthermore, several online communication tools were made available to facilitate remote student-teacher interaction. Although several students initially experienced internet-connection related problems and lacked overview of the virtual workspace itself, students indicated during focus group sessions that using Virtual Labstore instead of teacher-prepared lists stimulated thinking about how to perform their experiments. Additionally, they acknowledged the value of being able to look for materials and communicate with their teacher independently of physical location. In conclusion, Virtual Labstore positively affected students' perceptions on learning about experimental design and increased student-teacher interaction flexibility. However, Wi-Fi-stability should be checked, and time should be allocated for student-training before use.

Keywords: second life, 3D virtual learning environment, inquiry-based learning, warehouse, store, shop, laboratory education, research education, distance education

Introduction

In the undergraduate educational program 'Biology and Medical Laboratory Research' of the University of Applied Sciences Leiden (The Netherlands), students are trained to become biomedical laboratory research technicians with a Bachelor of Science (B.Sc.) qualification. This program consists of several educational tracks, including a 'research track' in which research skills are taught, and a 'technical track', in which laboratory techniques are taught. Currently, we wish to implement inquiry-based research courses into our research track to stimulate scientific thinking and process skills.

Inquiry-based research courses focus on formulating the research question and hypothesis, developing the experimental procedures, performing laboratory experiments to collect data, and critically evaluating obtained results (French & Russell, 2006). Different levels of inquiry can be distinguished, based on who provides the problem, who provides the experimental procedures, whether the solution or outcome is known and the extent of the instructor's involvement (Johnson, 2009; Herron, 1971). Generally, when the research question and the experimental procedures are provided by the teacher, the inquiry is categorized as structured. Presently, our aim is to implement more open inquiry-based research courses, in which the research question is still provided by the teacher, but the procedures are devised and performed by the students and the outcome is unknown. This situation mimics the situation in the work field for which our students are trained.

In our previous research courses, students received a research question and a pre-determined teacher-prepared list of selected laboratory materials which could be used to perform the experiments. Since these materials lists were presented at the beginning of the research course, we believe that the students' line of thinking was already directed towards the 'right' experimental approach. Hence, this type of inquiry would be classified as somewhere between structured and guided inquiry (Johnson, 2009). Our aim is to expose our students to a more open inquiry-based research experience in which they develop their own experimental procedures. To do this we discarded the teacher-prepared materials lists and replaced them with an online warehouse system that displays the complete collection of laboratory materials available in our university. This online laboratory warehouse system enabled the students to select their own materials for their projects, and the selected materials were easily accessed by the teacher afterwards. Moreover, in order to mimic a real laboratory situation and raise cost awareness of our students, the products were price-tagged (Brown, 2006).

During the research courses, students discuss their research projects with their teachers in scheduled class meetings. Many of our students do not live in the vicinity of our university and often work on the preparation part of their research projects off-campus. Therefore, we additionally aimed to increase the flexibility of student-teacher interactions throughout the research courses by removing the need for a physical class space. This was achieved by implementing extra online sessions in addition to our scheduled face-to-face meetings in which students were able to discuss their projects with the teacher.

To integrate the warehouse system with an online communication platform, we developed Virtual Labstore. This is a three-dimensional (3D) virtual learning environment (3DVLE) in which avatars can interact with the laboratory warehouse system and communicate with others using both audio and text-based applications. Although the warehouse system could be constructed with Microsoft Excel or Access and shared with Learning Management Systems (LMSs) such as Blackboard, 3D platforms, such as Second Life or Active Worlds (Hew & Cheung, 2010), are known to have positive effects on students' appreciation of the learning environment (Tapsis et al., 2012). Over the years, many different 3DVLEs have become available and the majority of these 3DVLEs were designed as a) tools for learning support, b) simulation environments, c) social interaction environments and d) game environments (Reisoğlu et al., 2017). Furthermore, different 3DVLEs employ diverse learning strategies and have been used for a wide range of topics such as language learning, science, health science, the field of business and computer science (Reisoğlu et al., 2017). 3DVLEs that are situated in a laboratory setting generally consist of interactive simulations. Examples include Labster (Bonde et al., 2014), the Second World Immersive Future Teaching (SWIFT) project (Rudman et al., 2010 and Rueda et al., 2018) and Earthlab Education Island (Vrellis et al., 2016). In Labster, pre-defined virtual laboratory exercises can be performed in which students also have to answer questions and receive immediate feedback throughout the exercises. In the SWIFT project, a genetic testing lab is simulated, and students can communicate with each other and teachers to facilitate discussion about the assignment. The Earthlab Education Island was used to combine a problem-based learning strategy with a laboratory simulation about the laws of reflection and trigonometry. However, although several 3DVLEs are available in which interactive laboratories are simulated and communication between users is possible, no 3DVLE has been available that simulates an interactive laboratory warehouse system which can be used to prepare real-world laboratory experiments. Hence, the newly developed Virtual Labstore constitutes a unique addition to currently existing 3DVLEs.

Virtual Labstore contains the complete collection of reagents and hardware present in our university, including product information and price-tags. Students can walk around freely in Virtual Labstore using an avatar and order the materials they need. Furthermore, a financial budget is assigned to each student group, which limits the amount of materials they can collect to perform their research. The limit of the financial budget is pre-determined by the teacher.

Additionally, Virtual Labstore provides a virtual communication platform in which students can interact with their teacher, independently of physical location. It contains both verbal and non-verbal communication tools as well as teaching applications such as blackboard and PowerPoint screens.

Virtual Labstore was implemented in a second-year research course in which students had to show whether apoptosis was induced in Jurkat cells after treatment with the cytostatic etoposide. Afterwards, several students were interviewed in two separate focus groups. Our key objective was to get an initial impression of how students experience 1) designing experiments with Virtual Labstore and 2) communication with the teacher in Virtual Labstore. For that purpose, we chose to perform a limited qualitative study with student focus groups since these have the advantage that students are able to follow up on each other's ideas and opinions through facilitated discussion (Leung, 2009).

Methods

Using Virtual Labstore

Prior to the research course, the Virtual Labstore environment was developed by the Spanish company 'The Education District' (Virtway). The system works with three different websites. The first site is the Virtual Labstore space itself in which students and teachers can walk around and collect materials they need. The second website is the back-end site in which users are added, students and teachers are assigned to classes and information about materials is imported into the system. The third website is the management site in which the virtual space itself is managed. We positioned all the materials in the virtual space and included protocols, tutorials and a blackboard screen using this site. This was simply done by adding links to available internet websites.

For each class (16-18 students), a clone of the Virtual Labstore space was generated in the management site and students were assigned. These clones were only accessible for the students of the assigned classes. All the students obtained accounts for Virtual Labstore. Each student research group, consisting of two students, received a virtual financial budget of €10.000 (approximately 11,000 USD) which could be used to collect the materials they needed for their research project.

At the beginning of the research course, a short demonstration of Virtual Labstore was given to the students during a kick-off lecture. Additionally, students received a manual which gave a description on how to use Virtual Labstore. Similarly, the teachers involved also received a short demonstration and a manual describing the tool.

The students worked in pairs and assigned to assess whether the cytostatic etoposide is able to induce apoptosis in Jurkat cells. For this purpose, they had to develop a working plan in which they outlined the experimental procedures they wanted to perform. This working plan was assessed by the teacher and provided with feedback. Students were given the opportunity to ask questions and discuss matters related to the research assignment during both in-class sessions and virtual sessions. One of these virtual sessions was held outside regular office hours. Working plans that were finished were sent to the teacher via email. Additionally, students finalized their purchase of materials in the Virtual Labstore by pressing 'check out'. Immediately afterwards, the teacher automatically received an email with the ordered materials. Based on the working plans and purchases made in the Virtual Labstore, the teacher decided whether students were allowed to perform their experiments in the laboratory. In case of an insufficient working plan, students could send in an approved version and make new purchases in the Virtual Labstore. After the experiments were performed and the results were analyzed, students wrote a research report which was graded by the teacher.

The different functionalities of Virtual Labstore are displayed in Figures 1 to 13.

Evaluation of Virtual Labstore

On completion of the research course, two separate focus groups were organized. In total, 8 students were randomly selected for participation in one of these focus groups.

Questions were asked about the use of Virtual Labstore with regard to a) the materials students needed for their research projects, b) the possibility of asking questions virtually, c) the visibility of costs of the materials and a predetermined financial budget and d) the overall added value when working on a research question and developing a working plan. The focus groups were audio recorded and afterwards the transcribed text was analyzed according to the procedures of qualitative content analysis described by Erlingsson and Brysiewicz (Erlingsson & Brysiewicz, 2017). In short, meaning units were extracted from the transcribed texts and labeled with descriptive codes. Codes describing the same issue were further grouped into categories. This analysis was performed by two individuals independently of each other. Subsequently, the categories were compared, and consensus was reached on the final categories.

Additionally, a short evaluation session was held with the teachers that were involved. Questions were asked about the advantaged and disadvantages of working with Virtual Labstore to develop the working plan. The answers were written down by the researcher and similarly analyzed as described above.

Results

After performing qualitative content analysis, 8 categories emerged from the students' answers.

Category 1: Experienced added value of using Virtual Labstore instead of teacher-defined lists

According to the students, using Virtual Labstore instead of teacher-prepared lists stimulated their thinking about which materials were needed for what purpose and enhanced their preparation. Students noted that when teacher-defined materials lists were available, as was the case in previous research courses, they knew they needed all the materials in these lists. In their opinion, this simplified the research assignment. When using the Virtual Labstore instead, students indicated that since they had to select their materials themselves, they really had to think more independently about how they were going to address the research question and perform the experiments. They indicated that this made them better prepared for the laboratory work afterwards.

Category 2: Experienced added value of working virtually in Virtual Labstore.

Students acknowledged the benefits of being able to have virtual question sessions with the teacher and looking for materials in the Virtual Labstore. The fact that Virtual Labstore is accessible in every location with an internet connection eliminates the need to travel to a certain physical location. This allowed the students to be more flexible. However, some students mentioned that they preferred face to face communication due to lack of eye contact / non-verbal communication in the virtual space. Students also mentioned that they could get accustomed to communicating virtually.

Category 3: The teacher must take the lead during virtual question sessions.

During virtual question sessions, communicating in the virtual space could be difficult and chaotic; at certain moments, students were talking all at once because it was not clear who was going to talk first. However, students indicated that if the teacher took the lead during the virtual sessions, this problem was solved.

Category 4: Cost awareness and financial constraints

Students indicated that the price information made them more aware of the costs of laboratory work. This potentially provides a more realistic situation since there is a financial constraint on the experimental choices students can make. However, since the budget was very high, it did not constrain students' work.

Category 5: Improving Virtual Labstore by providing a better overview of the available materials.

Several students indicated that they lacked an overview of the Virtual Labstore. They had difficulties finding the materials and protocols they needed and were therefore hampered when making their research working plans. A suggestion was made to provide information on the contents of the cupboards at the location of the cupboard itself.

Category 6: Several aspects of working in the Virtual Labstore space itself are unpractical.

Students experienced several difficulties which were related to working in the Virtual Labstore space itself. Sometimes, students blocked each other's view in front of the cupboards. Additionally, it is possible that different students have the same avatar, and although names can be put on top of the avatars, this is very unpractical. Finally, sometimes the information on the little jars in the cupboards was difficult to read.

Category 7: Increase 'ease of use' by providing training for students and teachers

Students complained about the difficulty of using the Virtual Labstore. They proposed several solutions for this problem, including tutorials and demonstration movies about Virtual Labstore and a guided tour in the Virtual Labstore. They also proposed additional training for the teachers involved.

Category 8: Technical issues

Students experienced several technical issues, most of which were related to suboptimal access to the internet. These included problems with accessing the Virtual Labstore, slow loading of the avatars and materials lists and downloading protocols. When using Apple computers, product information was not visible.

In addition to the two focus groups with students, a short evaluation session was held with the teachers that were involved.

Several advantages of using the Virtual Labstore were mentioned. According to one teacher, students asked more questions and seemed to be less afraid to ask 'stupid' questions since they did not seem to be hampered by peer pressure. Another teacher added that in her experience, their questions were more specific than before. For example, they asked things such as *'can I use this cell proliferation kit to demonstrate that apoptosis has occurred?'* instead of *'what exactly are we supposed to do?'*. Additionally, specific questions about the datasheets (spec sheets) that accompany the materials in the Virtual Labstore were asked. Teachers noted that the large number of materials available in Virtual Labstore called for a more thorough preparation by the students.

Disadvantages that were mentioned included 1) technical issues similar to those experienced by the students and 2) difficulties with finding materials in the Virtual Labstore and finding protocols for carrying out the experiments.

Discussion

To increase the level of inquiry of our research courses towards open inquiry, we developed Virtual Labstore. We circumvented the use of teacher-prepared lists of selected laboratory materials by creating a virtual warehouse containing all available laboratory materials in our university. Students received a research question, worked on their experimental designs and subsequently selected the necessary materials in Virtual Labstore, taking into account product and price information.

Our key objective was to assess how students experienced the replacement of the teacher-prepared lists of necessary materials with Virtual Labstore and how it affected their perception of designing experiments. The students indicated that they needed to think more independently during the experimental design phase which enhanced their preparation. According to the teachers, the students asked more specific questions about the research strategy as well as the protocols they found attached to the materials present in Virtual Labstore. These observations could indicate that the students demonstrated an increased sense of 'agency' in relation to the research project. Agency combined with mentorship has been described as a positive indicator for student project ownership and this has been associated with a positive research experience (Hanauer et al., 2012). The current findings are also in line with a previous report in which students felt they had to think and analyze more throughout a guided inquiry-based physics course (Parappilly et al., 2013).

Our secondary objective was to assess how students experienced the flexibility of student-teacher interactions through the use of virtual class-rooms. Scheduled sessions with the teacher in Virtual Labstore enabled students to ask questions about their working plans. Students indicated that working independently of a physical location increased their flexibility. However, some students mentioned that they preferred face-to-face communication since eye contact and non-verbal communication were absent but that they could become accustomed to communicating virtually. One teacher observed that working in a virtual world lowers the strain of shyness, which is in line with a similar observation made by Pfeil et al. (2009). Hence, we conclude that using Virtual Labstore for virtual educational sessions is a useful tool to increase the flexibility of our educational program.

In order to raise cost awareness of our students, all the materials were realistically price-tagged, and student research groups received a financial budget. Students appreciated the price information but noticed that the provided financial budget was unrealistically high. For this study, we did not wish to hamper students' work by providing a budget that was too small. Therefore, we chose a high budget that would not limit students' purchases. However, by monitoring the current purchases of the students, we obtained indications for a more realistic budget which we can use in the future. Preliminary calculations have estimated this realistic budget to be a couple of hundred euro's (similar amount in USD) for the current research course. We believe that providing students with a realistic financial budget could be very helpful when working in a more open inquiry setting since it may facilitate self-regulation of the magnitude of students' projects. In the future, it would be interesting to compare the current student learning experiences with those of students who obtained a realistic budget.

Throughout the Virtual Labstore sessions, several aspects of the virtual space itself, including overcrowding, were experienced as unpractical by the students. In the real world, students perceive insufficient working space in the laboratory as a deficiency in the learning environment (Sandström et al., 2013). Generally, an uncomfortable physical learning space which hampers performing tasks has a negative effect on learning (Sjöblom et al., 2016) and this might also be true for virtual learning spaces. Winkelmann et al. (2017) reported that using virtual laboratory environments is regarded as helpful when space and equipment are limited in the real-world laboratory. We therefore believe that we should take advantage of the fact that in virtual learning spaces, practical issues such as overcrowding can easily be resolved. In the future, overcrowding may be prevented by having less students entering at the same time. One way to achieve this is by creating separate clones for each student pair. Additionally, the email addresses of the students are currently displayed on top of their avatars as a means to identify the avatars. However, these long email addresses hampered avatar identification when more students were closely together in the virtual space. Virtual Labstore uses the login names of the students as identification names for the avatars. Since we were using Virtual Labstore with more than 100 students, it seemed most practical to use students' email addresses as login names because these were readily available. However, to better facilitate the identification of the avatars, we are planning to create short login names for the students in the future. Interestingly, using a personal avatar increased students' sense of telepresence and copresence throughout an English as Foreign Language course performed in Active Worlds (Peterson, 2006). Hence, we are currently also thinking of developing and implementing the ability to customize avatars in order to better facilitate student identification and to further enhance students' learning experience.

Students indicated that they had difficulties using Virtual Labstore for the first time and finding their way inside the virtual space. One student suggested providing content information near the cupboards. This content information was already available when clicking on the signs above the cupboards but apparently this was not noticed by all the students. In order to improve ease of use of Virtual Labstore, students indicated that they needed more and better instruction on how to use Virtual Labstore. This is in line with previous reports (Pfeil et al., 2009; Salmon et al., 2010) in which the importance of investing enough time in getting students and tutors started with the virtual system was mentioned. In the current research course, a short introduction was given to the students during a kick off meeting in which other information about the course was given as well. Additionally, an online manual about the virtual platform was provided. Clearly, this was not sufficient for many of the students to be able to use the platform efficiently. Therefore, we plan to organize several dedicated meetings about the platform in the future, including a demonstration of a pre-recorded virtual tour and a tutorial with exercises about the different functionalities that are present in this virtual world. Besides training the tutors in how to use the virtual space, Pfeil et al. (2009) also emphasized the importance of training tutors in how to teach and moderate teaching sessions in the virtual space. For example, our students reported that the teacher has to take the lead to facilitate a structured virtual class meeting. Hence, before using Virtual Labstore in the future, a training program for both students and teachers should be developed and time should be invested to execute and evaluate this program.

Several technical problems were encountered by some students, including loading elements of the Virtual Labstore and loading the Virtual Labstore environment itself. These problems were mainly related to a hampered connection to the internet. Most likely this was caused by low Wi-Fi stability and not so much by low internet speed (personal communication with The Education District, Virtway). Warburton (2009) already mentioned technical issues in 2009 which can cause 'lags' that occur when too many objects within a single location cause slow loading. These lags can lead to a frustrating experience and pose a barrier to successfully implementing a virtual world. Therefore, in order to have a positive Virtual Labstore experience, a good internet connection is crucial and when Wi-Fi stability is low, a wired Ethernet connection might be used as an alternative instead. Thus, facilitating a proper internet connection needs to be taken into account when students access Virtual Labstore both at home and on campus.

At present, our educational program consists of several educational tracks. The research courses are part of the research track which focuses on teaching research skills. Our technical track includes educational courses about laboratory techniques. As mentioned before, there are other 3DVLEs that simulate laboratory environments, such as Labster (Bonde et al., 2014). Labster is a platform in which pre-defined virtual laboratory exercises are simulated and in which students are allowed to make mistakes. In our opinion, this is a very interesting tool for learning how to perform laboratory experiments and it could be very helpful in our technical track to prepare our students for real-world experiments. In the future, we therefore aim to use Virtual Labstore and Labster separately for our research and technical tracks respectively.

In conclusion, Virtual Labstore is a promising tool which can facilitate a more open inquiry-based laboratory research course and increase the flexibility of student-teacher interactions. Virtual Labstore can easily be adjusted by teachers with new laboratory techniques, protocols and tutorials. Challenges that need to be addressed in the future are the development of a training program for both students and teachers. Finally, the current study indicated that using Virtual Labstore enhanced students' perception of their own thinking about experimental design. However, future studies are needed to evaluate whether students' actual ability to design experiments also increases by using Virtual Labstore.

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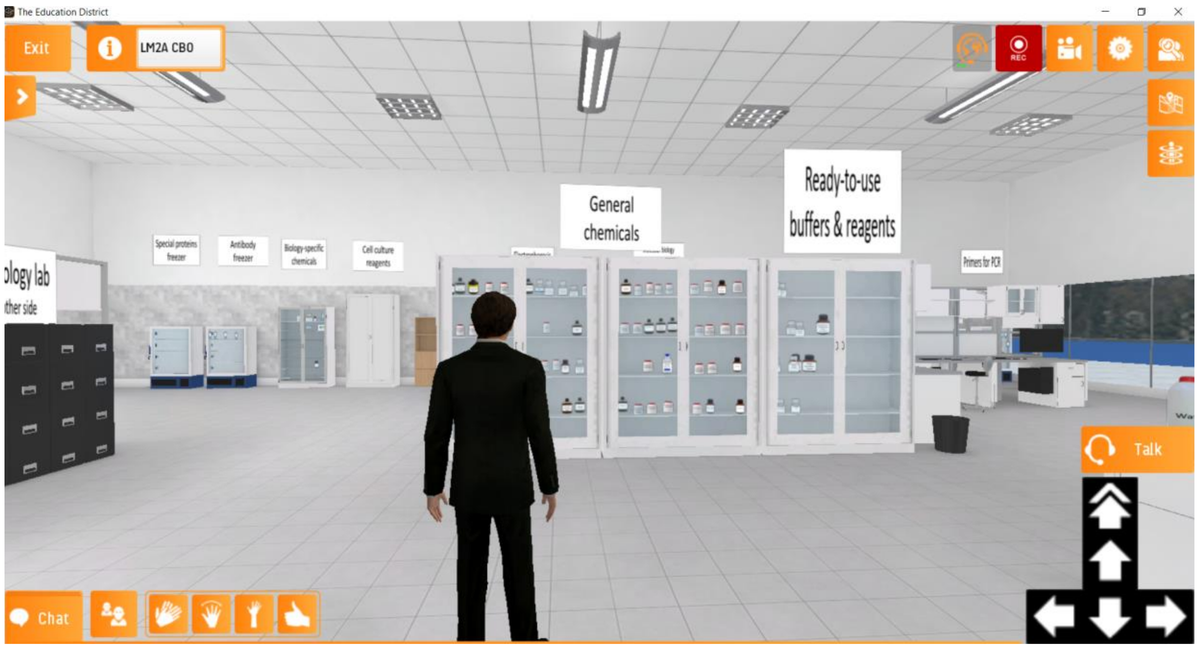
Appendix

Figure 1.

General overview of Virtual Labstore.



The arrow buttons are used for walking through the virtual space. Talk and chat buttons are present for communication. Additionally, hand gesture buttons are available and optionally, a recording button can be added as well.

Figure 2.

Close-up of the General Chemicals cupboard.

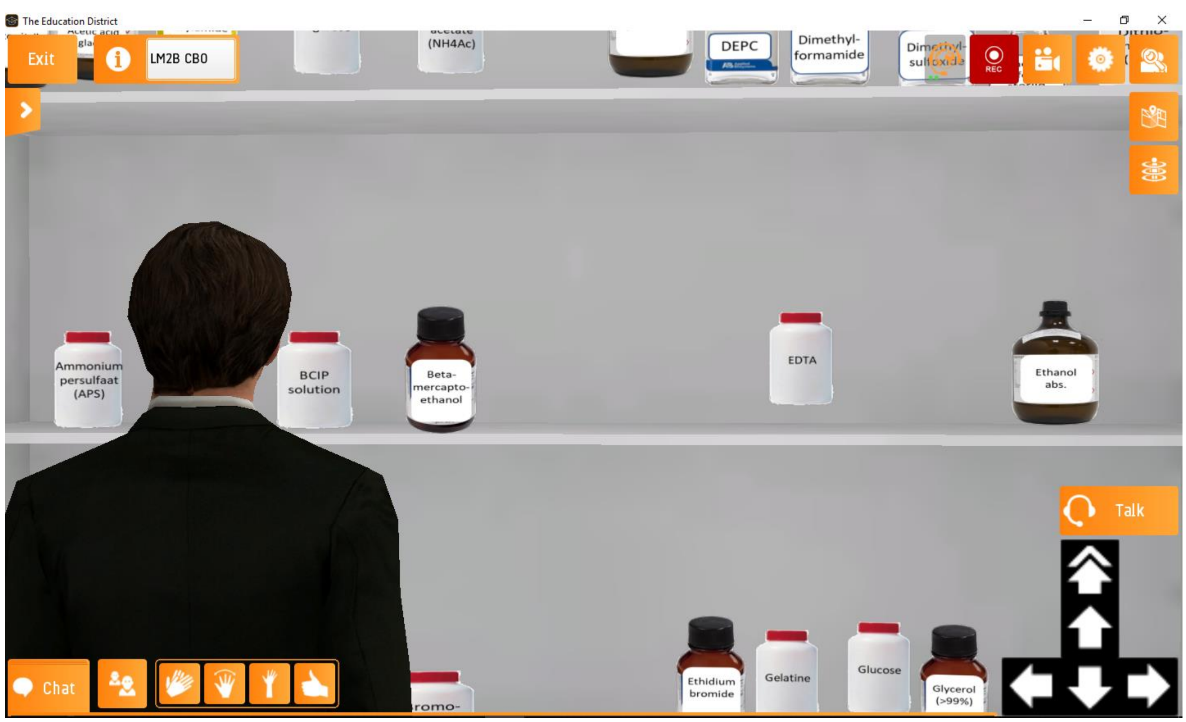
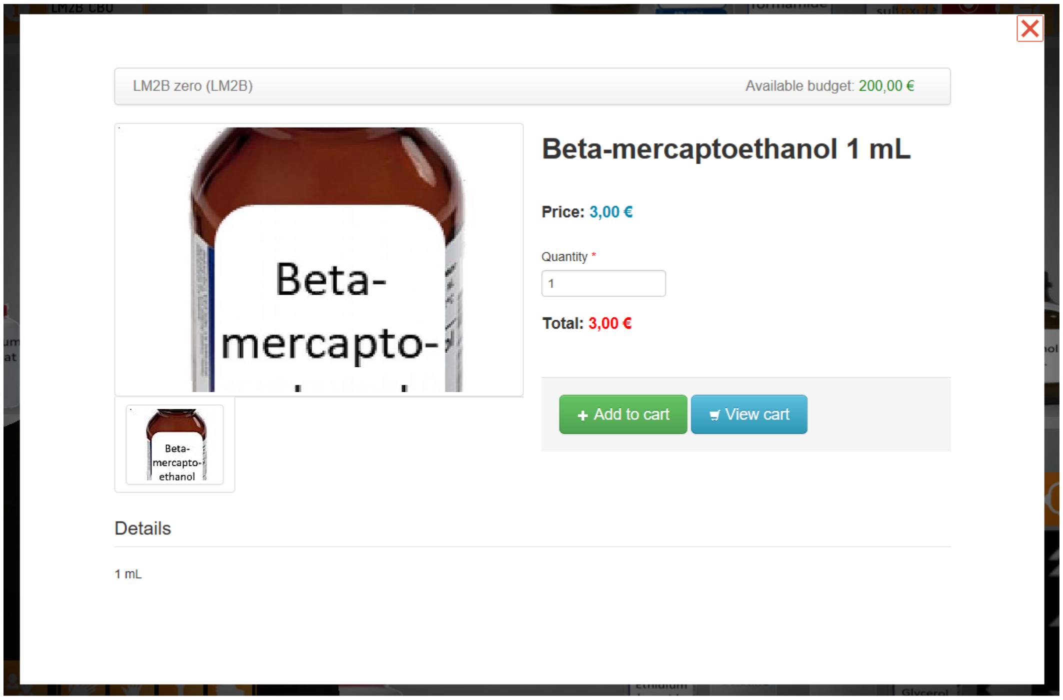


Figure 3.

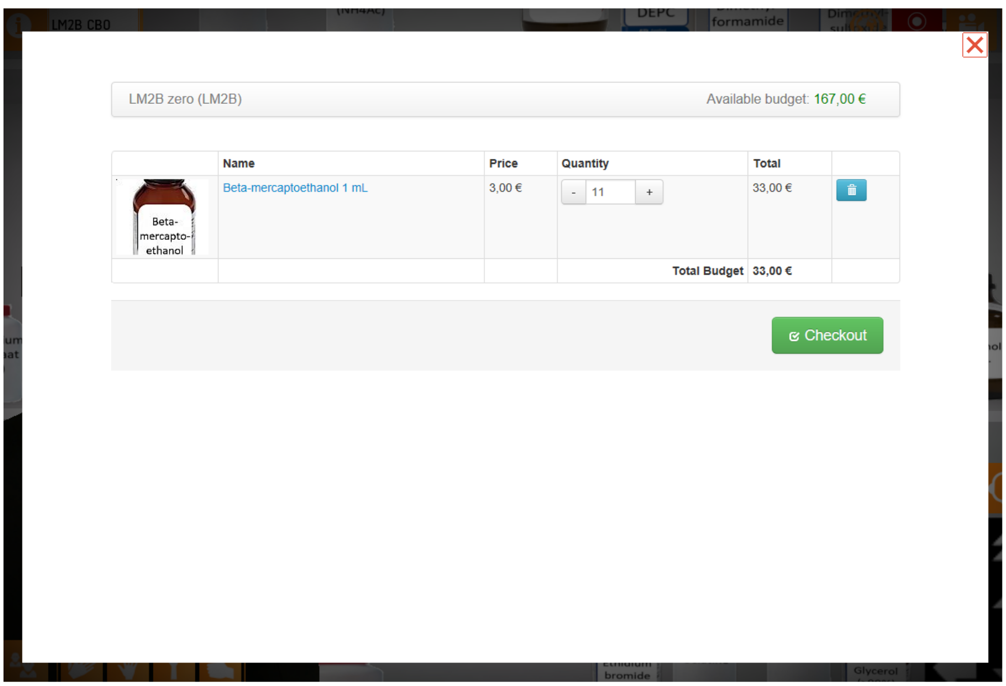
Product buying functionality.



After clicking on the beta-mercapto-ethanol bottle in Figure 2, the current screen is displayed. Price information and details of the product are depicted. In the upper right, the available financial budget can be seen. The product can be bought by clicking on the 'add to cart' button.

Figure 4.

Product buying functionality.



After ordering 11 bottles of beta-mercapto-ethanol in Figure 3, the 'view cart button' was pressed and the current screen is depicted in which all the ordered items are listed.

Figure 5.

List of the ordered materials the teacher receives after student pressed the ‘checkout’ button in Figure 4.

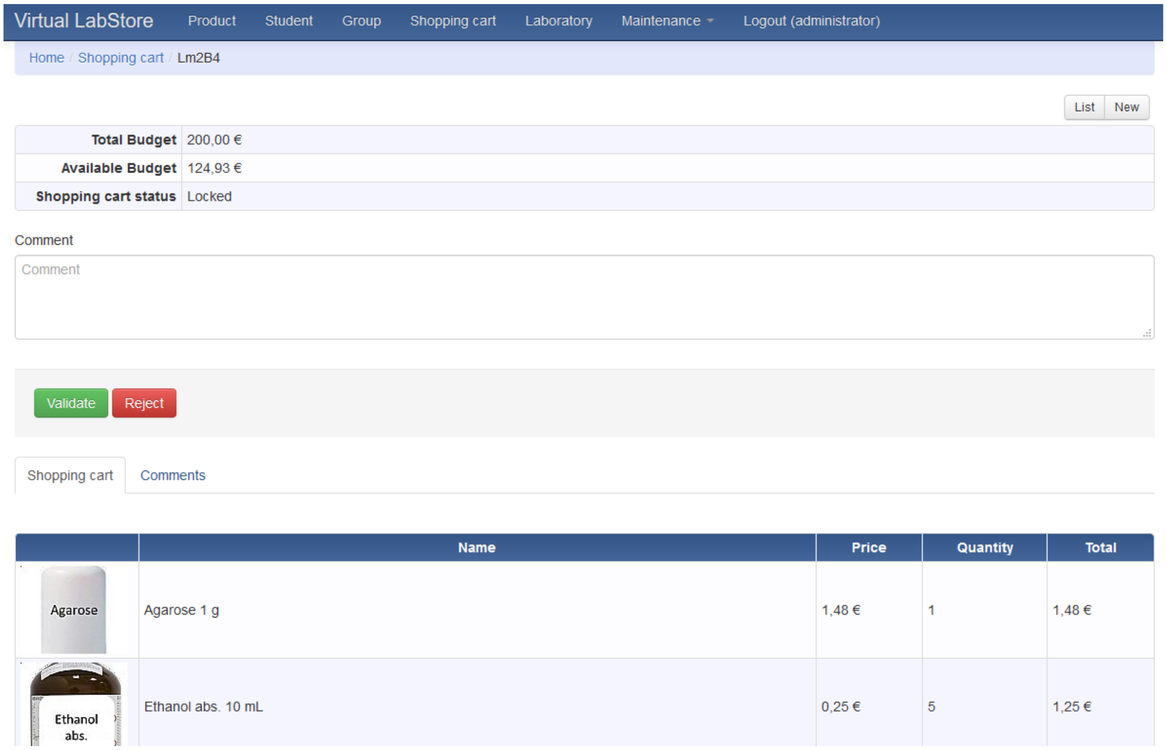
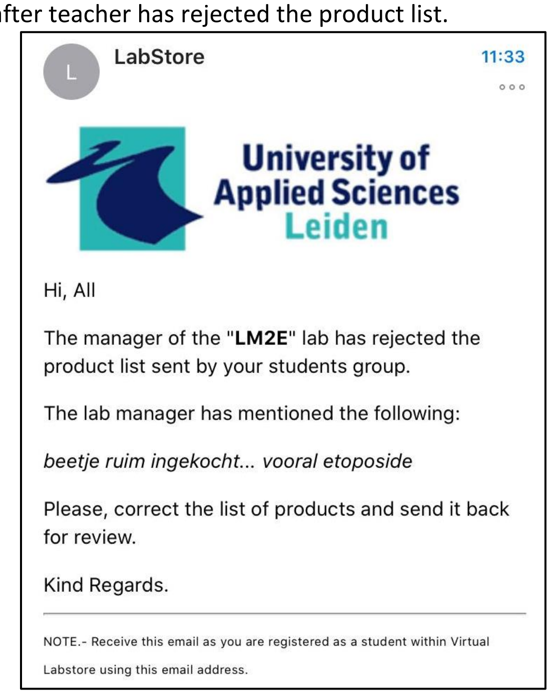


Figure 6.

Message received by students after teacher has rejected the product list.



After the teacher has pressed the ‘reject’ button in Figure 5, the message depicted in this figure is sent to the students via email. The Dutch sentence ‘*beetje ruim ingekocht, vooral etoposide*’ translates as ‘*you bought a lot of etoposide*’.

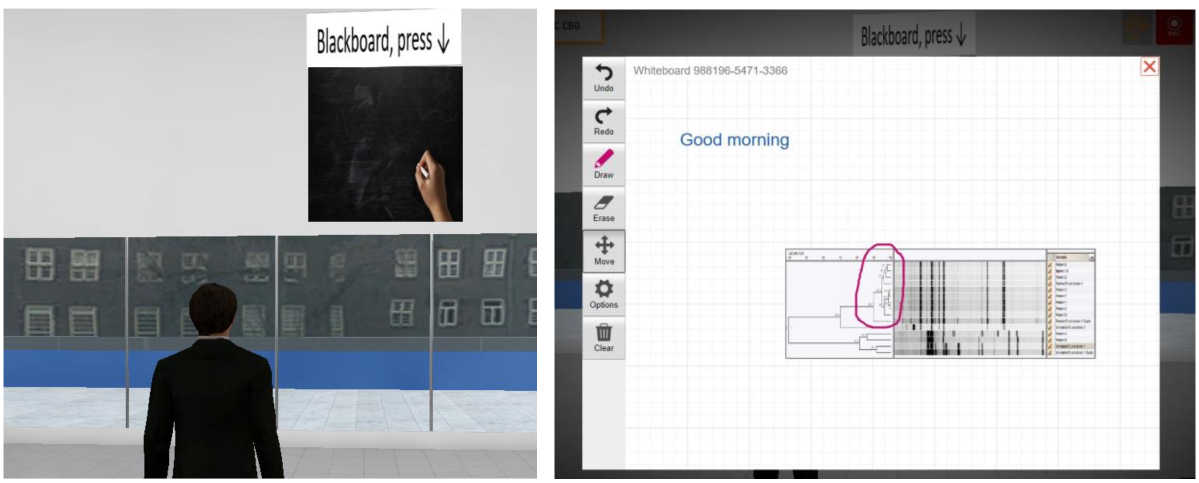
Figure 7.

Virtual class session.

Students’ name tags (email addresses) have been blurred for privacy reasons. The arrow indicates the teacher.

Figure 8.

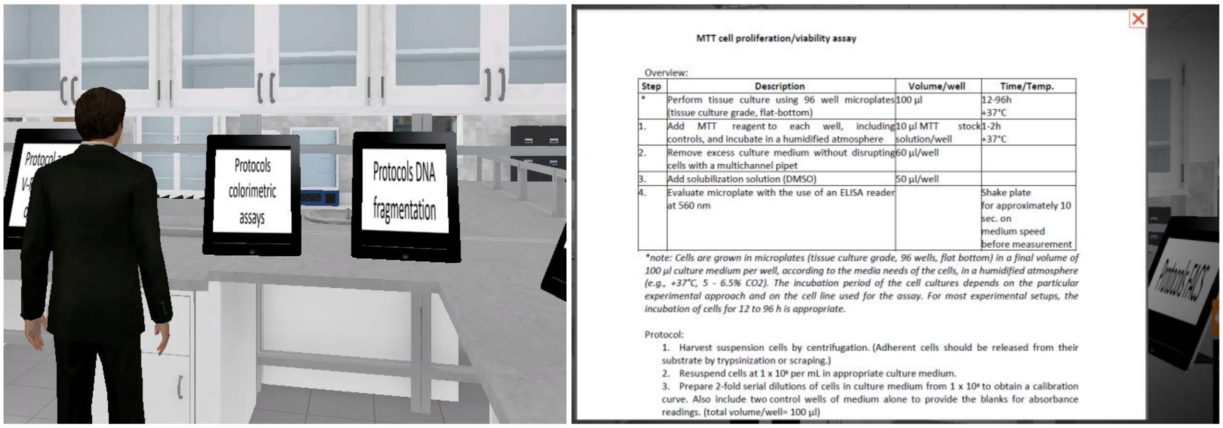
Blackboard application in Virtual Labstore.



An internet link to WhiteboardFox (© 2014 Springbok Solutions Ltd) was used to include this blackboard into the Virtual Labstore. After pressing the blackboard on the left, the screen on the right opens. In this screen, a gel image was uploaded. While using the blackboard, students and teachers can still use the talk functionality.

Figure 9.

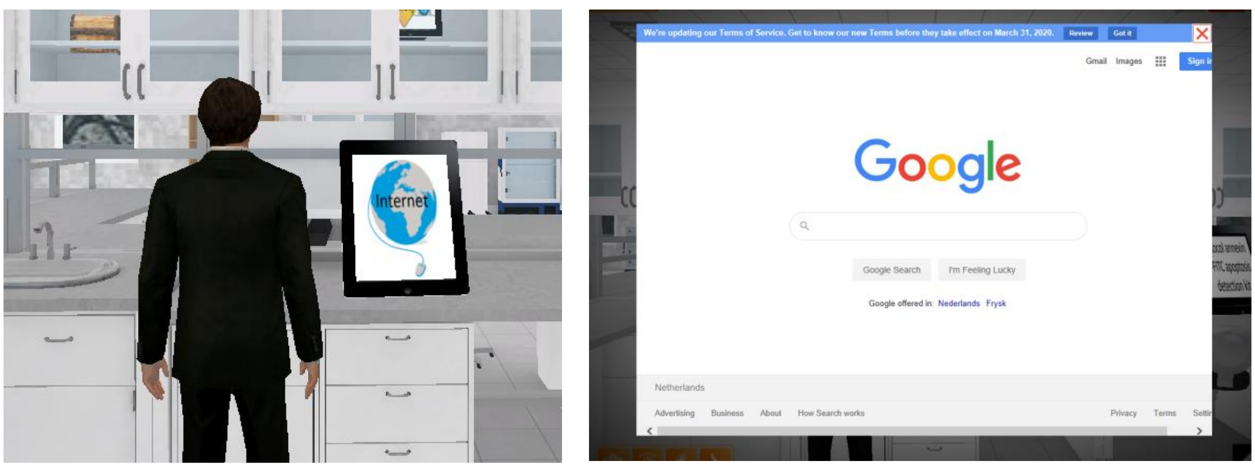
Protocols can be added to the Virtual Labstore.



Protocols can be added to the Virtual Labstore by adding them manually or by inserting internet website links into the management site.

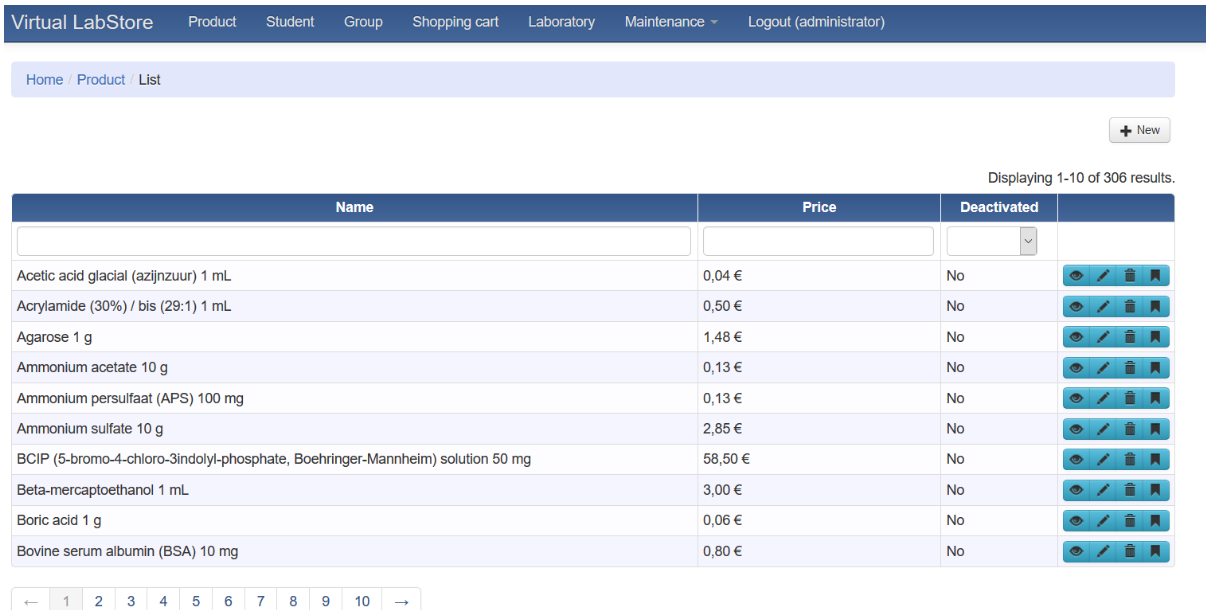
Figure 10.

An example of an inserted internet connection.



When clicking he 'internet panel' on the left, the website on the right opens.

Figure 11.
Managing products in the back-end site.

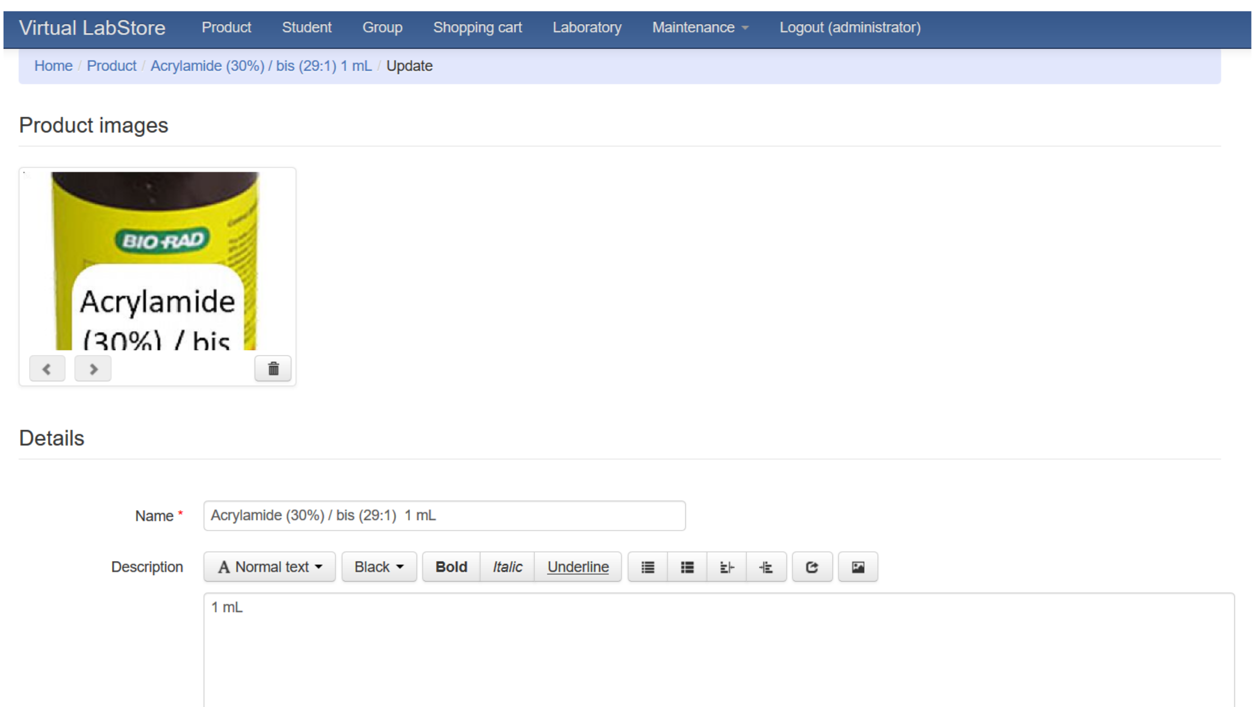


Name	Price	Deactivated	
Acetic acid glacial (azijnzuur) 1 mL	0,04 €	No	
Acrylamide (30%) / bis (29:1) 1 mL	0,50 €	No	
Agarose 1 g	1,48 €	No	
Ammonium acetate 10 g	0,13 €	No	
Ammonium persulfaat (APS) 100 mg	0,13 €	No	
Ammonium sulfate 10 g	2,85 €	No	
BCIP (5-bromo-4-chloro-3indolyl-phosphate, Boehringer-Mannheim) solution 50 mg	58,50 €	No	
Beta-mercaptoethanol 1 mL	3,00 €	No	
Boric acid 1 g	0,06 €	No	
Bovine serum albumin (BSA) 10 mg	0,80 €	No	

New products are added by pressing the '+New' button.

Figure 12.

Managing products in the back-end site.



Products can be adjusted and descriptions can be added.

Figure 13.

Overall view of the management site.

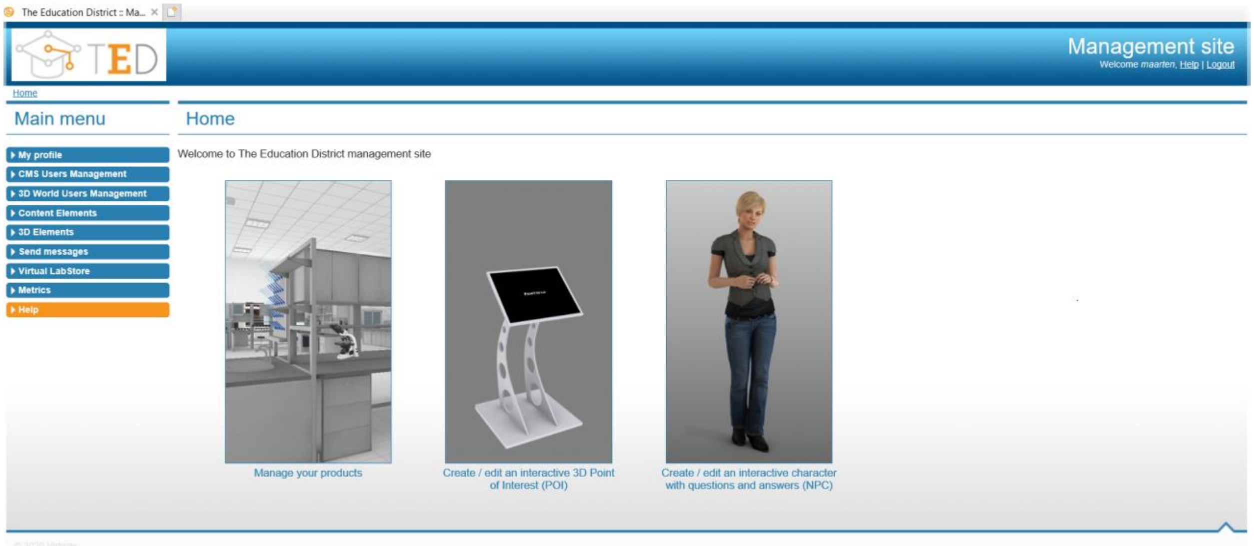


Figure 14.

The product positioning tool in the management site.

Both the arrow buttons and T, R, S coordinates can be used for positioning of products. Size of the products can be adjusted with X, Y and Z buttons. Products can be rotated as well.

Using Simulations to Support Undergraduate Elementary Preservice Teachers' Biological Understanding of Natural Selection

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ABSTRACT

Natural Selection is prevalent throughout life science learning standards across K-12 contexts. Additionally, undergraduates who are interested in the fields of biology and education must also be well informed on the topic, as it is foundational to some biology research and necessary to touch upon within elementary and secondary classrooms. This pilot study explores the understanding of undergraduate preservice teachers' understanding of evolution mediated by a simulation called SEPUP, which explains evolution within generations of bird populations. By utilizing this simulation, we were able to identify how students engaged with a simulation to think about natural selection. Through analyzing student artifacts, findings suggest that employing a simulation to teach natural selection afforded students' a positive learning experience which likely could not have been easily achieved otherwise. This work provides recommendations for technology usage (e.g. creating meaningful reflection questions which target content) and development (e.g. ensure simulations provide a clear scope and scale around time) for evolution simulations.

Keywords: natural selection; undergraduate learning; simulations

Introduction

Natural selection is a staple learning standard taught at all grade levels. Despite this, some students may lack a baseline understanding of it. The concept of natural selection is first introduced to elementary students in third grade as they begin to explore the concepts of inheritance, variation, and diversity in traits. These concepts, pursuant to Standards 3-LS4-2 Biological Evolution: Unity and Diversity as well as 3-LS3-1 Heredity: Inheritance and Variation of Traits (NGSS, 2013), begin to form the base of a structure that ultimately lends itself to understanding pivotal biological concepts and theories. In order to explore comprehension of this topic at the college level, we employed the use of a simulation encompassed within a classroom session focused on science and technology learning. This pilot study aimed to measure the practicality of using a web-based simulation in order to instruct a group of undergraduate preservice science educators regarding the topic of natural selection, answering the research question:

> How do elementary preservice teachers conceptualize natural selection when engaging with a simulation?

Background Literature

There are three main facets of science education literature that we have identified in contributing to the background of this study: science education as it relates to natural selection, preservice elementary teachers' misconceptions about evolution, and the use of simulations to garner scientific understanding.

Science Education in Biology & Natural Selection

Understanding natural selection is not limited to primary or secondary educational levels—it is a fundamental pillar of understanding biology, and this is carried into the collegiate level of teaching, as well. Research has shown that undergraduate students still harbor misconceptions surrounding natural selection even after taking one semester of introductory biology in college (Nehm and Reilly, 2007). The results of this study determined that although 99% of the students enrolled in the course had heard of natural selection or had been taught it previously, only a few students were able to effectively provide an accurate definition of these concepts. This is important to note, as many of these students will progress onto teaching in science classrooms prior to identifying their own misconceptions. Nehm and Reilly (2007) discuss the importance of capturing the variation in experiences that individual students may have, and this assists in providing greater insight into what students think. Studies have been conducted with regard to formative assessments and how to “squash” misconceptions regarding natural selection (Furtak, 2012). Studies have demonstrated that biology majors share several misconceptions about natural selection, despite having previously taken biology courses (Furtak, 2012; Nehm & Reilly, 2007). Thus, it is important to address these misconceptions at various grade levels, including working with preservice science educators to ensure they are comfortable cultivating the concepts they are tasked with teaching.

Natural selection learning has been studied extensively in populations of students majoring in biology, however there is a lack of literature examining preservice teachers' conceptions and understanding of natural selection (Nehm & Reilly, 2007; Furtak, 2012; Sickel & Friedrichsen, 2015). As some teachers progress onto teaching general science courses, it’s essential to address these misconceptions at all grade levels. Further research could be conducted to assess the extent of the knowledge preservice teachers possess when fully matriculating into the lead educator in a classroom.

Preservice Teachers’ Experiences in Evolution

In the realm of teaching evolutionary concepts at both an introductory (e.g. the standards set forth by the NGSS for elementary studies) as well as the collegiate level (e.g. course standards for teaching preservice science educators), multiple methods have been employed to demonstrate the concept of natural selection. One such method is the use of simulations, which is the method that we have chosen for exploring evolution learning in preservice science teachers. Research has shown that teachers who do not fully grasp natural selection and evolution are likely to pass down that misunderstanding to the students they teach, no matter the grade level (Schrein et al., 2009). In this study conducted by Schrien et al. (2009), teachers were asked to create their own concept maps about evolution. The teachers were given a focus question and were encouraged to include 15-20 words or short phrases in their concept map. Between all of the participants, three conceptual categories were identified: misconceptions about Darwin’s discoveries, mechanisms of evolutionary change, and the meaning of commonly used terms in evolutionary biology (Schrein et al., 2009). These misconceptions surrounding evolution may permeate into the classroom, highlighted through elementary classroom studies (Emmons et al., 2017). Emmons et al. (2017) highlights the misconceptions about natural selection that elementary students may have learned during their time in the classroom. While natural selection is considered a learning standard for grades 6-12, elementary students can quickly develop misconceptions surrounding natural selection at a young age (Emmons et al., 2017). If these misconstrued ideas are formed when a student is still in elementary school, they may carry this with them throughout their educational journey.

Natural selection is a unit that both teachers and students struggle with, as students need more tangible models to understand the complexity of the subject at hand (Sickel & Friedrichsen, 2015). By employing the use of a simulation, we hope to further enhance preservice teachers’ understanding of natural selection.

Using Simulations to Teach Biology Concepts

Research has demonstrated science cognition and learning are improved when students are given the opportunity to interact with their environment while also participating in inquiry-based science interventions (Alexander & Russo, 2010; Chen et al., 2014; Dyer & Elsenpeter, 2018). By allowing students to explore the natural environment around them, such as with Alexander and Russo’s (2010) work, students demonstrated more engagement and understanding of scientific concepts in relation to nature. This idea of providing students with real life, interactive examples can be transposed onto other fields within the sciences. Simulations are an incredibly useful tool to demonstrate concepts that would otherwise be impractical or unethical to perform in the real world (Ameerbakhsh et al., 2019).

Problem-based simulations have also been developed over the years to introduce students to real-world situations, such as Kumar and Sherwood’s (2007) study measuring a group of science education students’ skills after studying water quality. Research has shown that simulations are beneficial in situations where the phenomena occurring is difficult to visualize, such as generational change and population shifts over thousands of years. However, without proper scaffolding, simulations can also cause confusion for students who do not have a baseline understanding of the concept at hand (Sickel & Friedrichsen, 2015). This highlights the importance of a simulation with clear instructions and descriptions in order to provide the necessary background information that a student may need. For this study, we chose the Science Education for Public Understanding Program (SEPUP) simulation on

Natural Selection, found at the web address https://sepuplhs.org/high/sgi/teachers/evolution_act11_sim.html). SEPUP is a non-profit, research-based program housed at the University of California, Berkeley. Several researchers have tested the viability of this simulation, as well as the National Science Foundation, and it is considered a valuable tool for teaching and learning scientific concepts (Nagle et al., 2016; National Science Foundation, 1997; Ogens & Koker, 1995). Our reasoning for choosing this simulation was the functionality on multiple computer systems as well as the accessibility and simplicity of the program. Over several years, this simulation has received robust positive feedback from researchers and educators alike and can be applied to a variety of grade levels. By employing this pilot study, we hope to contribute further to the literature improving the quality of tools available to teach preservice science educators who plan on working in general science classrooms.

Methods

Students were asked to participate in learning about natural selection through an online simulation. Worksheets were used that asked questions about the data from the simulation and about natural selection. Students were asked to document and reflect about their experience both during and after the simulation. These artifacts capture the diversity of ways individuals within a group experience this phenomenon (Lister et al., 2004). Additionally, observational notes were taken throughout the class period. This assisted in identifying the connections between the different groups of students, and how or why they did or did not learn new concepts about natural selection.

We utilized a phenomenological framework to analyze our data and to investigate the scientific experience of the participants. The focus of a phenomenographic study is not based on the individual experiences of the subject involved, but rather a comprehensive understanding of how the collective subjects experience any given phenomenon (Bodner & Orgill, 2007). Phenomenography is a powerful tool to interpret data received from student responses. Phenomenography assists researchers in identifying individual learning differences within an experimental sample, and this helps paint an overall picture of how students vary in learning about a specific topic. Orgill (2007) provides several examples of chemistry and science education studies based in the methodological framework of phenomenography. There are such examples as Aguirre & Haggerty's (1995) study researching preservice teachers' conceptions of learning. These researchers were interested in learning about how preservice teachers described their learning experience over the course of the academic year. Other studies, such as Yung's (2001) work, were interested in learning more about biology teachers' conceptions of fairness in implementing school-based assessments. This study considered that all biology teachers may approach school-based assessments in various ways, and it is important to how their conceptions were formed. Orgill's (2004) work, however, details the primary reason why we were interested in using phenomenography as a framework—Orgill states that they were interested in the experience that instructors and students had using analogies in biochemistry. Orgill was not concerned with their own experiences in chemistry education, but instead were concerned of the students and instructors they worked with (Orgill, 2004). By focusing on the multiple ways that students may experience this content, phenomenography may be used to effectively describe how each student may vary in their own experience of learning.

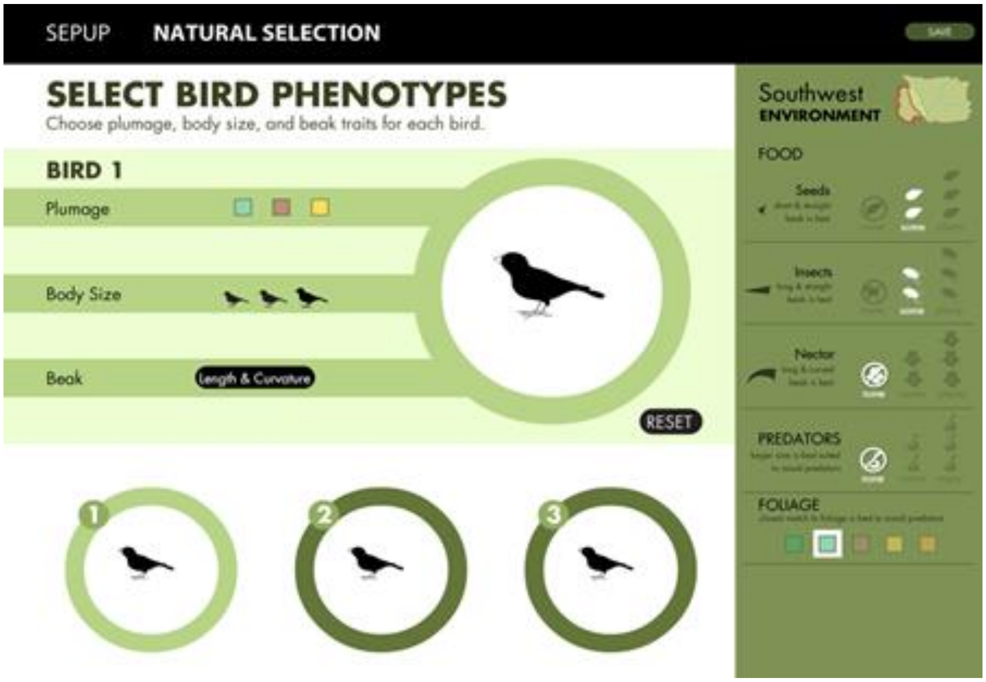
Participants & Context

Participants in this study were 25 elementary preservice teachers enrolled in a teacher education program at a large southwestern university. After all artifacts were submitted, only 14 students submitted all documents and were considered for this study. This university is a Hispanic and minority-serving institution, with a population of elementary preservice teachers reflective of the local population. The undergraduate students were Juniors and Seniors, enrolled in a 16-week science methods course typically required the semester before student teaching.

Simulation Description and Classroom Intervention

We began the intervention by outlining the benefits and drawbacks of using technology in the classroom. The students were then asked about their knowledge of natural selection, and answers were given regarding overarching concepts such as Darwinism and "survival of the fittest." We instructed students to record their thoughts and feelings regarding the discussion and the use of technology throughout the class period, including before, during, and after the simulation. Additionally, students were asked to record their answers regarding the simulation on a worksheet (Appendix).

Figure 1.
Student view of SEPUP Simulation.



Environment information, including food, predators, and foliage, are listed in the right-hand window.

The simulation begins by having students choose the traits that they would like to see in three different bird populations. These traits are based on computer-generated information regarding food availability in the environment, the color of the foliage in the environment, and any present predators. This information was provided in a sidebar window of the simulation, and descriptions were listed for what would work best for that particular environment (Figure 1).

Students were able to make choices such as beak size and curvature, plumage color, and body size. The different phenotypic choices made by the students influenced the increase or decrease of each bird population on the premise of natural selection. The simulation displays this message prior to beginning.

> "This part of the simulation represents 500,000 years. A bird population exists in the southwestern portion of the island. During this time, mutations may change the fitness of some birds and their descendants in the environment.
>
> Birds with traits that enhance their fitness are more likely to survive and reproduce."

The simulation provides information on the changes in the population every 50,000 years, pausing for students to record their population numbers and observe any changes (i.e. a mutation causes beaks to grow larger, allowing that population access to larger insects). This occurs ten times, providing students with the population numbers up to 500,000 years. Mutations could be randomly introduced by the simulation at every 50,000-year mark. These mutations could change any of the three phenotypic traits, and lead to increasing, decreasing, or not affecting fitness. The students were asked to write down both their starting bird population numbers as well as their final population numbers. Students were provided ~10 minutes of guided, step by step instruction to ensure they understood the functionality of the simulation. The students created a table to record their results over time and took note of changes that occurred. Once everyone reached the 500,000-year mark, the students were asked to compare and contrast their starting populations to their final populations with other students in the class. The students recorded their thoughts on their respective worksheets, followed by answering the discussion questions once the simulation was complete. Next, students were allowed to start the simulation again, and freely investigate how their bird population evolved on their own for ~ 20 minutes, as instructors circulated around the room, only answering questions as needed.

Data Collection

Three student artifacts were collected: a worksheet focused on the content of the simulation (Figures 2 & 3), reflection answers collected in student notebooks and during the posttest (Figures 4 & 5), and observational notes from the classroom group.

discussion, taken as needed. Students were asked to answer questions regarding the simulation itself, as well as documenting any observations or instances of increased understanding during the simulation. Students were also asked to interact with other student groups in order to compare and contrast their different populations. Complete data was collected from 14 of the 25 students who participated in this study.

Student Worksheets

The simulation was accompanied by a modified worksheet from the unit SEPUP: Science & Global Issues – Natural Selection. This worksheet contained questions regarding natural selection that were to be answered throughout the class (Appendix A).

Student Reflections

After using the simulation and completing the worksheet, students were asked a series of questions with the intent to discover their understanding of the simulation. Figures 4 and 5 highlight student responses within their notebooks, while the questions below were answered by students once the simulation was completed.

1. Today we explored the implementation of technology within the classroom in order to assist with science learning by the use of simulations. Did you find this beneficial in solidifying your knowledge of natural selection, and why? What worked for you personally and for your group overall?

2. Using technology to introduce new concepts is beneficial if it is applicable to different classrooms.

Figure 2.

Student Worksheet.

Environmental Condition	Bird Phenotype Best Suited
Seeds	Short & Straight beak is best
Edible Insects	long & Straight beak is best
Nectar	long & Curved beak is best
Predators	larger size best suited to avoid Predators
Foliage Color	Closest Match to foliage is to avoid Predators

Student answers regarding the best bird phenotype based on the environmental conditions.

Figure 3.

Student Worksheet.

1. Discuss how the bird populations changed over the course of the 500,000 years. For example, what types of mutations occurred? Under what circumstances were the offspring more or less fit as a result of the mutation?

Bird 1 and 2 remained fairly constant, Bird 3 thrived and grew steadily in number over time. Bird 1's beak decreased in size and Bird 3's body decreased in size. No mutations for bird 2

2. Were your ideas about the fitness of each phenotype you selected correct? Explain why or why not.

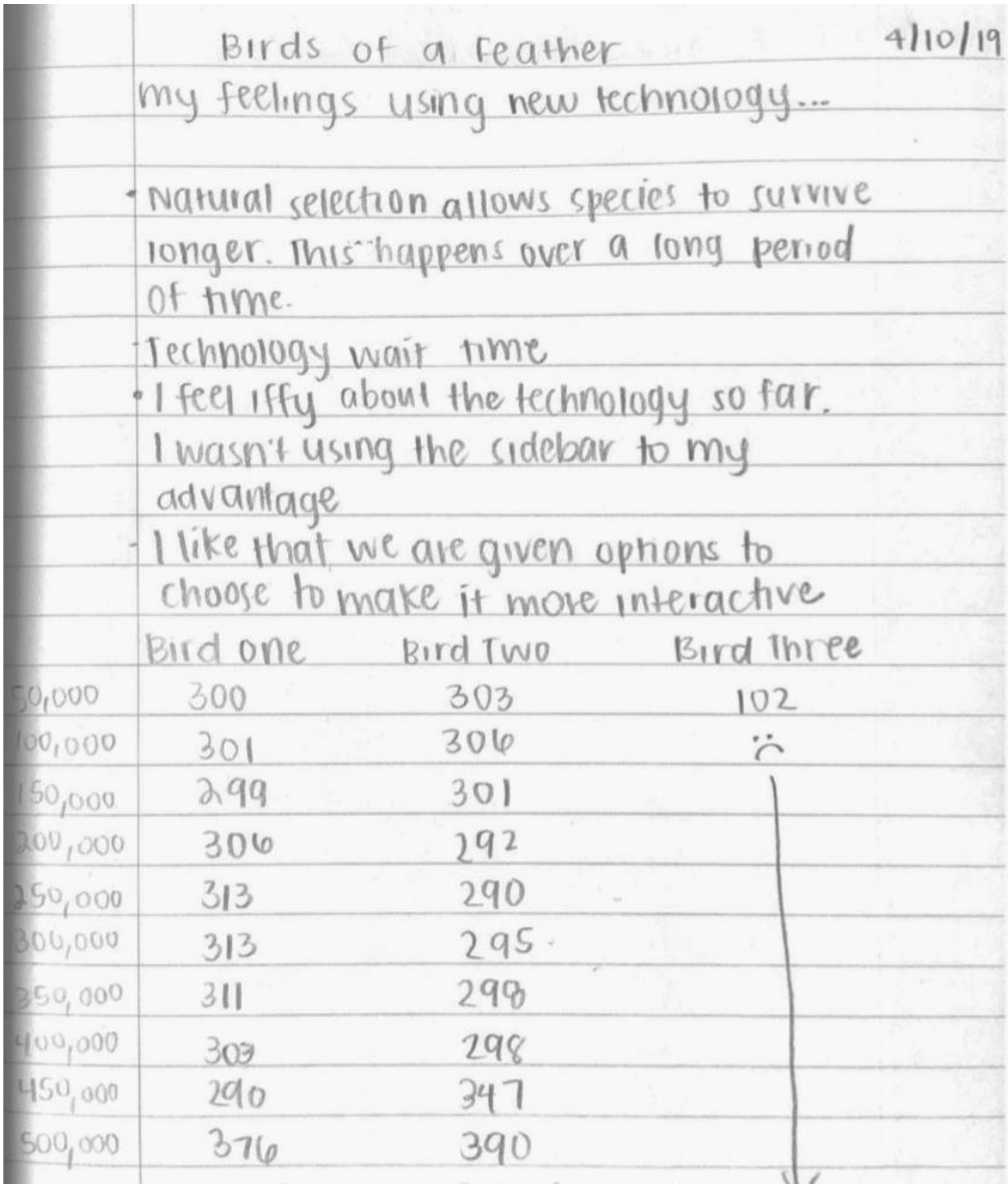
Yes, we chose our traits based on food and predators shown. None of our birds died out.

3 Compare how the bird populations changed compared to the bird populations of another group of students. There simulation should have yielded different results. Record the similarities and differences you notice.

Our Bird 3 decreased in size and thrived and another group's bird who decreased in size also thrived. Color is irrelevant.

A student's written answers to the discussion questions

Figure 4.
Responses from Student 2.


Birds of a Feather 4/10/19
my feelings using new technology...

- Natural selection allows species to survive longer. This happens over a long period of time.

Technology wait time
- I feel iffy about the technology so far. I wasn't using the sidebar to my advantage
- I like that we are given options to choose to make it more interactive

	Bird one	Bird Two	Bird Three
50,000	300	303	102
100,000	301	306	:(
150,000	299	301	
200,000	306	292	
250,000	313	290	
300,000	313	295	
350,000	311	298	
400,000	303	298	
450,000	290	347	
500,000	376	390	

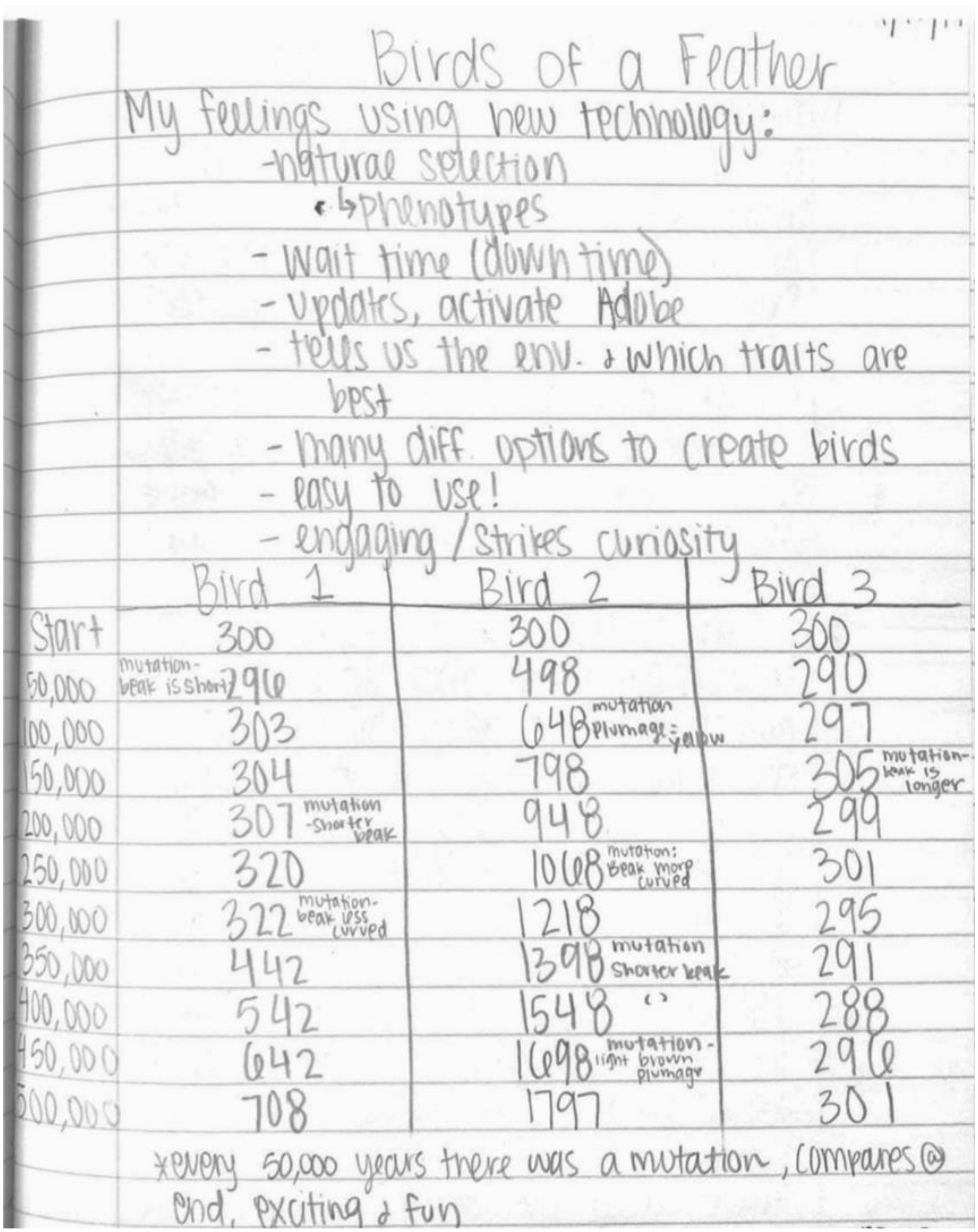
How would you potentially implement this strategy within your own classrooms? (You are not limited to this specific simulation—instead, focus on the use of simulations to teach relevant concepts overall). What parts do you think would be beneficial for your classes, and what would you change?

Data Analysis

Responses to the modified natural selection worksheet were recorded and analyzed for instances of understanding natural selection and the variation of evolutionary traits over time. Responses from students contained within the student reflection papers were qualitatively coded via open coding using MAXQDA software for Macintosh systems. Instances of positive technology experience and enhanced learning were recorded. Analyzing the reflection papers assisted in highlighting the ways in which different students experience different concepts.

Figure 5.

Responses from Student 3.



Birds of a Feather

My feelings using new technology:

- natural selection
  - ↳ phenotypes
- wait time (down time)
- updates, activate Adobe
- tells us the env. & which traits are best
- many diff. options to create birds
- easy to use!
- engaging / strikes curiosity

	Bird 1	Bird 2	Bird 3
Start	300	300	300
50,000	mutation- beak is short 296	498	290
100,000	303	648 mutation plumage = yellow	297
150,000	304	798	305 mutation- beak is longer
200,000	307 mutation - shorter beak	948	299
250,000	320	1068 mutation: Beak more curved	301
300,000	322 mutation- beak less curved	1218	295
350,000	442	1398 mutation shorter beak	291
400,000	542	1548 "	288
450,000	642	1698 mutation- light brown plumage	296
500,000	708	1797	301

*every 50,000 years there was a mutation, compares @ end, exciting & fun

Findings

First, we will focus on how students conceptualized natural selection. Many students were surprised at the outcome, noting that their initial predictions did not match the outcome of their populations. For the first round of the simulation, one student wrote, “we thought the big bird would survive and he did not. I thought red would survive but it did not. Same with curved beak.” They then shared ideas regarding which traits conferred a higher fitness for their populations and identified what phenotypic variations allowed their populations to survive. Some students noted how the environment set the tone for the direction of the mutations, while some mutations were entirely random. Observational notes demonstrated that when students spoke with other groups they were able to come to the correct conclusion that mutations do contribute to natural selection, thus expanding upon their understanding of natural selection and the processes that act upon populations over time.

Student A, for example, was able to identify when mutations occurred during the simulation and related those mutations to either an increase or a decrease in the population. This demonstrated a level of understanding that was not explicitly outlined in the simulation, which assisted this student in solidifying their knowledge surrounding natural selection. They wrote, “Bird 1 changed size and color because there was a mutation picked up. At 150,000 [years] a mutation made their offspring better mates.” Student B drew the conclusion that color was irrelevant in this portion of the simulation, as there were no predators present in the environment, so the birds did not need to blend in with the foliage. During the classroom observation and discussion, they shared this information with their groupmates and the instructors. Since they chose their traits based off of the food and predators shown, the only influencing factor on their population numbers were the traits affecting food acquisition. Additionally, we found that there was variance in students’ depth of understanding. While some students reported using the simulation to understand population changes over time, such as describing which populations increased or decreased, other students were able to connect the different phenotypic variations with an increase or decrease of fitness. One student noted the following in their reflection paper:

> “The use of simulations was more beneficial in solidifying my knowledge of natural selection. It was more beneficial because I got to physically see changes overtime, see the mutations, see what characteristics are better than others when it comes to surviving, and it was interactive.”

With regard to the use of the simulation itself, student feedback was overwhelmingly positive, with only a few students stating that they didn’t understand the material as they felt it was outside of the scope of their classrooms. One student stated:

> “I found the use of simulation more beneficial in expanding my knowledge of natural selection. This simulation was really fun to see what happened to the birds and the explanation that was given about the changes it underwent. We could make guesses about why those changes happened. Generally it was to increase the ability to get food. I thought our bird that was a brown colour and did not blend into the foliage would have died off and it survived. It did not thrive like the other two birds that were green, but it did not go extinct either.”

Overall, the discussion was robust, with many students actively engaged in the material and sharing that they were more comfortable with the topic of natural selection after completing this simulation. One student notes the impact of the simulation on their knowledge of natural selection, which was further confirmed by their correct assessment that changes and mutations contribute to natural selection: “Before coming to class I have a very broad idea of natural selection and how it works. I believe all aspects of the lesson contributed to my knowledge.” In speaking about applying this simulation to their own future classrooms, this same student wrote that they would like to use this simulation, as “[my students] are able to see the change over years within minutes and have actual representations plus descriptions of the changes/mutations.”

We were able to determine that this group of students responded positively to simulations that broke down important evolutionary concepts. The level of student engagement was noteworthy, as one student (Student BC) discussed wanting to continue to use this simulation at home in order to develop their knowledge of natural selection. By analyzing the student responses to both the worksheet and open-ended discussion questions, we were able to gain insight with a small, focused view of the impact of simulations on elementary preservice teachers.

Discussion

Our work further contributes to the existing literature by demonstrating the effectiveness of meaningful, interactive simulations with regard to teaching important biological concepts to elementary preservice science educators. By teaching elementary preservice science educators about the importance of hands on, interactive learning, we may further develop tools that contribute to a larger understanding of biology at an earlier age.

Research focusing on how preservice teachers learn concepts they will eventually be teaching is essential to creating a strong base of educators. Currently, students may be lacking in their knowledge of baseline biological concepts, and efforts must be made to ensure all students are prepared for the educational workforce upon graduation (Nehm & Reilly, 2007). By introducing preservice teachers to the application and benefits of using simulations, we can better prepare them for implementation of these tools within their own classrooms (Ameerbakhsh et al., 2019). With regard to the scientific literature, there are several ways in which this research may contribute: first, it can assist in developing or improving simulations used to teach biological concepts. By asking students to consider the implementation of this at a variety of grade levels, it may open up the possibility of using meaningful, interactive simulations at all stages of classroom-based education.

Second, this research may contribute to improving the teaching of natural selection at a college level. Currently, even biology majors may struggle with properly understanding natural selection (Furtak, 2012; Nehm & Reilly, 2007). If students who are studying this evolutionary theory struggle with misconceptions surrounding it, it is reasonable to assume that preservice science teachers may also struggle with these concepts as well. This research can ideally address these gaps in learning to further assist students with addressing their misconceptions about natural selection.

Third, this project could impact individuals who create simulations and technology surrounding evolution. Teachers have a variety of concepts to cover at a relatively quick pace, so employing the use of an effective simulation may assist in properly teaching an otherwise intangible concept. Participants in this project all enjoyed using the simulation for different reasons-- student responses included terms such as “simple,”, “easy to use,” “engaging,” “fun,” and “easy to navigate.” Students were able to effectively use the simulation and focus more on the learning aspect of it as opposed to the navigation of the website. Ensuring future simulations attended to these ideas would improve the experience and potentially making students more open to engaging with the content. Having elements of time very clearly accentuated helps students frame the concept of evolution and, being able to watch populations change over time, helped this group of students conceptualize natural selection.

Limitations

The population size of the study is a limiting factor. The classroom had 14 students complete all of the work, so various approaches to conceptualizing natural selection may not all be identified within this group. Additionally, since these students are all preservice science teachers, they have been trained to recognize concepts such as metacognition and other educational scaffolding techniques. These students may be more aware of their own learning, which may either benefit or harm their initial responses to this study. By using phenomenography as a methodological approach, this could potentially mitigate these issues by highlighting the differences in learning styles.

Future Directions.

More research should be conducted to expand upon the similarities and differences present when students experience new concepts such as natural selection. Overall, this research contributes to the improvement of science teaching and learning, further developing tools to enhance science education in the classroom. Further work can be done to measure student responses to a variety of simulations, and whether the concepts learned through these simulations carry over into everyday classroom instruction. Creating a strong foundation and understanding of evolutionary concepts at an early age will prepare students to engage and understand science for years to come.

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Appendix

Lab: Natural Selection

(modified from Sepup: Science & Global Issues – Natural Selection)

Background: In this simulation you will investigate populations of birds living on an island. You will begin by selecting three birds that represent phenotypes for several traits in one population that lives in the southwest portion of the island. You will explore how this population changes over time in the southwest. Then you will explore how the population evolves over long time periods in various environments on other areas on the island.

Activity: Begin by visiting http://sepuplhs.org/high/sgi/teachers/evolution_act11_sim.html to open the simulation. The first simulation represents 500,000 years. During this time, mutations may alter the ability of some birds and their descendants to thrive in the environment. Birds with traits that enhance their fitness are more likely to survive and reproduce. In the southwest, your birds will encounter the environmental conditions listed in the table below. **Fill in the second column of the chart with the bird phenotypes that *you predict* would be are best suited for each of the conditions.**

Table 1:

Environmental Conditions and Bird Phenotype

Environmental Condition	**Bird Phenotype Best Suited**
Seeds	
Edible Insects	
Nectar	
Predators	
Foliage Color	

Watch the animation and record the changes occur in each bird population over time. **Not every box will be filled in – only when changes occur do you fill in a box.**

Table 2:

Changes in Bird Populations Over Time

	Bird Population One		Bird Population Two		Bird Population Three	
Years	# of Birds	Mutation	# of Birds	Mutation	# of Birds	Mutation
50,000						
100,000						
150,000						
200,000						
250,000						
300,000						
350,000						
400,000						
450,000						
500,000						

Student reflection:

1. Discuss how the bird populations changed over the course of the 500,000 years. For example, what types of mutations occurred? Under what circumstances were the offspring more or less fit as a result of the mutation?

2. Were your ideas about the fitness of each phenotype you selected correct? Explain why or why not.

3. Compare how the bird populations changed compared to the bird populations of another group of students. Their simulation should have yielded different results. Record the similarities and differences you notice.

Building Confidence: Engaging Students Through 3D Printing in Biology Courses

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Abstract

3D printing is a widely used technology in a number of STEM fields and can be incorporated into undergraduate education in order to engage students in active learning. Using the Technological Pedagogical Content Knowledge (TPACK) framework, this study examined student perceptions of completing 3D printing of a physical model in two different Biology courses, Anatomy and Physiology and Molecular Biology. Students completed surveys before and after engaging in a semester-long 3D printing project. Demographic information was also collected in order to assess student perceptions based on race and sex. Students reported increased confidence with 3D printing technology after completing their projects, and this effect occurred similarly across race and sex. Student attitudes towards their 3D printing experience were overwhelmingly positive, with general interest and excitement being the most common themes. These results suggest that 3D printing projects can be successfully implemented in undergraduate courses and generate positive student outcomes. Engaging women and underrepresented minority students with 3D printing technology may have significant implications for retention of these students in STEM programs.

Keywords: undergraduate, 3D printing, models, anatomy and physiology, molecular biology

Introduction

The goals of Vision and Change in Undergraduate Education include ensuring that undergraduate Biology courses are "active, outcome-oriented, inquiry-driven, and relevant" (AAAS, 2009). The use of active learning strategies has been shown to improve student learning and exam performance and reduce failure rates (Freeman et al., 2014). 3D printing is an active learning tool that is increasingly being utilized in both K-12 and higher education, where it has been applied across disciplines ranging from STEM to the arts and humanities (van Epps et al., 2015). There is rapid growth in careers related to 3D printing and a demand for skills in this field, which can be introduced in undergraduate curricula (Pernaa & Wiedmer, 2019). For biology and pre-health students, applications of 3D printing, including scientific research, biomedical engineering, medical device design, industrial manufacturing, and personalized medicine, are closely related to many of the existing and emerging careers that they intend to pursue (Bhatt & Szalinski, 2013).

The pedagogical rationale for this study is grounded in using modeling and simulations as outlined in the AAAS Vision and Change Core Competencies and Disciplinary Practice (AAAS, 2009), "Drawing-to-learn" with the use of technology (3D printing) to develop the drawing (Cromley, 2020), and the Technological Pedagogical Content Knowledge (TPACK) framework, which has been used extensively to assess the incorporation of technology into pedagogy (Pernaa & Wiedmer, 2019). While TPACK is widely used, its application to studies on 3D printing is not well established. To address this gap in knowledge, we examined student perceptions after actively engaging in 3D printing of a physical model. Our design allowed for evaluation of "pedagogy, technology, content, and their interaction at the same time" (Pernaa & Wiedmer, 2019). Our goal was to introduce students to 3D printing technology through instructor-guided inquiry, so that the students could print an object of their choosing based on a publicly available template. They then utilized their 3D model during class presentations in order to enhance three-dimensional understanding of one of their course concepts. The project was carried out in two different courses that target different student populations and address two different levels of biological scale: 1) a sophomore-level Anatomy and Physiology course sequence for non-Biology majors and 2) a combined undergraduate and graduate level Molecular Biology course taken by Biology and Biochemistry majors. Our project design is noteworthy because most previous references to the use of 3D printing in Anatomy and Physiology and Molecular Biology/Biochemistry involved a more passive incorporation of 3D printing – the use of non-student generated 3D printed artifacts to aid teaching/learning of a particular subject (Ford & Minshall, 2019). In our study, students actively selected their object to print, engaged directly in the 3D printing process, and applied their object to course material through in-class presentations.

3D Printing in Anatomy and Physiology

Use of physical 3D models to teach Anatomy significantly improves student performance during assessment compared to the use of textbooks and 3D computer models (Preece et al., 2013) and compared to virtual and physical organ dissection (Lombardi et al., 2014). Students also report increased levels of confidence after using physical 3D models (Preece et al., 2013). 3D printing provides one mechanism to use physical 3D models and has been integrated into Anatomy and Physiology education in a variety of ways including 3D printing replicas of human bones (AbouHashem et al., 2015), skeletal structures from different species (Thomas et al., 2016), and human cadaver prosections (McMenamin et al., 2014; Fredieu et al., 2015). Although there are a number of studies that have used 3D printed models in anatomy education, we are unaware of any that incorporate the actual process of 3D printing in an undergraduate Anatomy and Physiology course so that students gain direct experience with 3D printing technology. Therefore, this study explored student perceptions before and after completing a project that required learning the 3D printing process to produce a student-chosen anatomical model that was then used to help show and explain relevant anatomy to peers during a presentation on a clinical disorder.

3D Printing in Molecular Biology and Biochemistry

Molecular biology and biochemistry courses typically emphasize the connection between biological structure and function and often do so in the context of examining biological information flow and transformations of energy and matter at the molecular scale (AAAS, 2009, Brownell et al., 2014). However, three-dimensional structure-function relationships at molecular scale are difficult for students to visualize and comprehend (Tibell & Rundgren, 2010, Forbes-Lorman et al., 2016, Offerdahl et al., 2017). Tools such as physical ball-and-stick models and virtual models within software that allow students to visualize and manipulate molecules on a computer screen are widely used in chemistry, biochemistry, and molecular biology courses and have been shown to increase student learning related to structure-function relationships (Harris et al., 2009, Jaswal et al., 2013, Newman et al., 2018). 3D printing represents an additional option for generating detailed physical models that provide students with the opportunity to visualize and interact with molecular scale structure-function relationships.

3D printing has been used in molecular-scale courses in a variety of ways (Pernaa & Wiedmer, 2019, Pinger et al., 2020), including providing 3D printed models for students to handle and manipulate in order to emphasize particular structure-function relationships (Cooper & Oliver-Hoyo, 2017; Howell et al., 2018; Babilonia-Rosa et al., 2018) and students generating 3D printed objects related to a specified area of emphasis within a lab course (Meyer, 2015). There are fewer reported examples of an instructor-guided inquiry project approach similar to the one we employed where students in a non-laboratory molecular biology course were able to learn and apply the 3D printing process to the production of an object of their choosing that could be used to show and demonstrate molecular-level structure-function relationships to peers during a presentation of their individually written review papers (Letnikova & Xu, 2017).

Demographic Considerations

Gender differences in spatial ability have been previously reported, with women exhibiting lower abilities compared to men. These differences may be accounted for, at least in part, by cultural influence and years of education (Hoffman et al., 2011). For example, utilization of a 3D physical model in a cell and molecular biology course increased quiz scores for female students, but not male students. Women also self-reported greater understanding of molecular structure/function connection after using 3D physical models (Forbes-Lorman et al., 2016). Therefore, integration of 3D printing in undergraduate education may be experienced differently and/or show varied impact across demographics. Given the importance of spatial ability to understanding key concepts within STEM courses, incorporating 3D printing into undergraduate programs may have even greater implications for retaining women and underrepresented minorities in STEM programs. Therefore, this study also explored student confidence and attitudes toward 3D printing in STEM courses across demographics. We hypothesized that after a semester-long 3D printing project, students across demographics would report increased confidence with using 3D printing and a positive attitude towards this technology in both Anatomy and Physiology and Molecular Biology courses. We also predicted that students would report increased learning of course content based on the 3D printing experience.

Methods

Participants

The participants were undergraduate students and MS seeking graduate students at a public primarily undergraduate institution in South Carolina. Students were recruited from sophomore level Anatomy and Physiology courses (Summer 2019 and Fall 2019 semesters) or an upper-level combined undergraduate/graduate Molecular Biology course (Fall 2019).

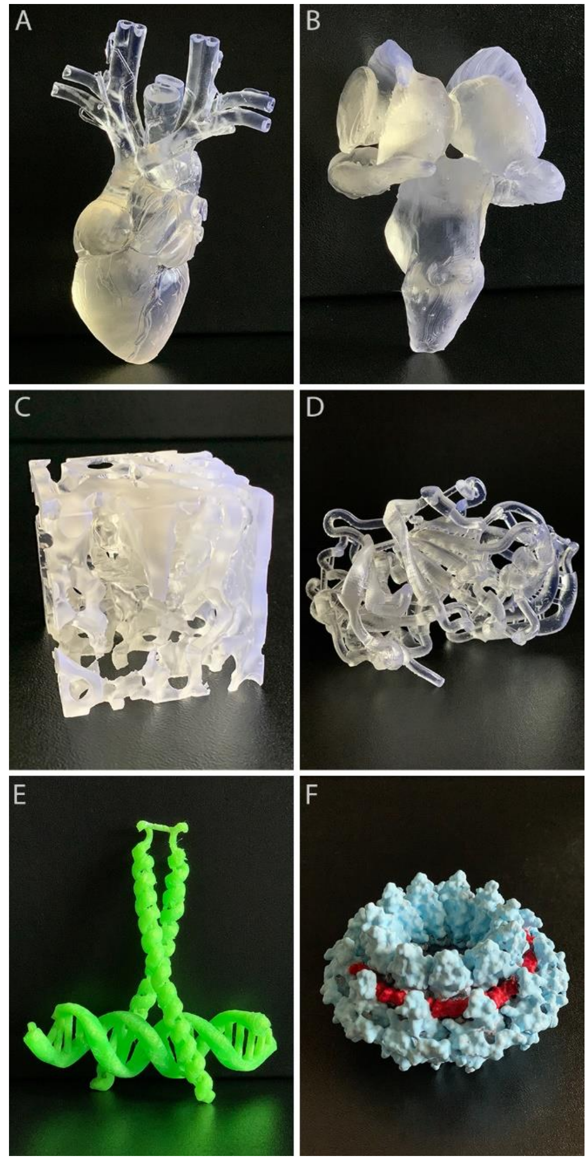
Procedure

Students were provided details of the project and recruited to participate in the study during the first week of class. All students completed the 3D printing project regardless of participation in the research study. Students were assigned a random 6-digit number to be used to match survey responses at the beginning and end of the semester, and those who agreed to participate completed an online survey via Qualtrics (Qualtrics, Provo, UT and Seattle, WA) at the beginning and the end of the term. The survey consisted of three sets of questions (Appendix A and B). The first set measured perceptions of 3D printing with two questions; interest in and confidence with 3D printing were measured using a 5-point Likert scale. The second set of questions measured attitudes toward 3D printing technology using an open-ended question and a set of 10 Likert questions that used a 5-point scale. The Likert questions were only administered at the end of the term and were grouped to measure the ease of use and usefulness of 3D printing technology (2 items; Cronbach's $\alpha = .57$), the perceived value of 3D printing to student learning (6 items; $\alpha = .84$), student desire to see other courses incorporate 3d printing technology (1 item), and how challenging the 3D printing process was (1 item). The final set of questions included demographic questions that were designed to capture diversity and inclusivity within the student population (Fernandez et al., 2016; The Human Rights Campaign, 2019). Anatomy and Physiology

In Anatomy and Physiology courses, students were assigned to groups of four or five using course averages to ensure a mix of academic performance in each group. Each group selected an organ or structure to 3D print and relate to a clinical disorder of their choosing (Appendix C). All objects were

Figure 1

Example 3D Prints



Example 3D Prints

Models printed in Anatomy and Physiology include heart (A) (MAAS Collection, 2016) and subcortical brain structures (B) (Kessler, 2015). Models printed in Molecular Biology include osteoporotic bone (C) (Barak & Black, 2018), ribbon models of the BACE1 enzyme (D) (Kuglstatter et al., 2008), the bZIP regions of a CREB dimer bound to DNA (E) (Schumacher et al., 2000), and a surface model of the RAD52 protein with ssDNA bound to its inner DNA binding site that was painted by the student (F) (Saotome et al., 2018).

printed using a Form2 printer and clear resin (Formlabs, Somerville, MA). Printing costs were covered by course fees. Students obtained .stl files from www.thingiverse.com, https://www.embodi3d.com, or https://3dprint.nih.gov, which all maintain creative commons copyright licenses. PreForm software (Formlabs, Somerville, MA) was used to scale and process the prints. Prints were post-processed in a 91% isopropyl alcohol rinse for 2 minutes, and then transferred to new 91% isopropyl alcohol and soaked overnight. Rafts and supports were removed after rinsing. Students delivered a group presentation about the model and its connection to a clinical disorder (Figure 1A and B).

Molecular Biology

In Molecular Biology, each student was required to 3D print an object to aid in the presentation of their individually written review paper on a topic of their choosing (Appendix D and E). While most students used the NIH 3D Print Exchange to find or generate a file for 3D printing as described below, students had the option to use any file that they could find or create. 3D printing was completed using a Form2 or a FlashForge Creator Pro printer with clear resin or PLA filament, respectively (Figure 1C-F). Printing costs were covered by grant funding or by the student (students could keep the object if they purchased it at cost).

A single class period held in a computer lab was designated to provide students with an overview of the 3D printing workflow. Students were assigned to read the Beltrame, et al. JoVE paper (2017) and watch the associated video prior to class. During class, students were introduced to fused deposition modeling (FDM) and stereolithography (SLA) 3D printing via YouTube videos. Students then practiced using the NIH 3D Print Exchange to find existing .stl files or import Protein Data Bank (.pdb) files and generate .stl files for sequential downstream processing in Autodesk Netfabb and Autodesk Meshmixer as described in Belatrame, et al. (2017). Both software are freely available. A live demonstration of the recommended processing steps and instructions for acquiring the processing software were provided in class. Processed .stl files were imported into PreForm for printing on the Form2 or Simplify3D for printing on the Creator Pro. These software slice the model and generate the code for printing according to the print settings input by the user. Form2 automatically adjusts temperature and UV laser settings based on the resin used and applies all settings to the gcode. The user adjusts the print resolution, and most students chose 25 microns for the finest resolution. Print settings recommended in Beltrame, et al. (2017) were used for printing on the Creator Pro. Form2 prints were post-processed as described above. Post-processing of Creator Pro and Form2 prints consisted of removal of the raft and supports.

Data Analysis

Data were analyzed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA) and SPSS Statistics (IBM, Armonk, NY). Students were asked to enter their 6-digit number on both the pre- and the post-survey to preserve anonymity. Unfortunately, 21 students entered the incorrect number or completed only one of the surveys, resulting in the inability to match several students' pre- and post-surveys. We report analyses on the full data set because some data (the attitudes toward 3D printing) were only administered at the end of the term, and we wanted to conduct the other analyses on the full sample as well. Analysis on the matched data produced qualitatively similar results. Primary analyses were a series of 2 (Course: Anatomy and Physiology, Molecular Biology) X 2 (Time: Pre, Post) between-subjects ANOVAs and t-tests on the survey items and $\chi 2$ analyses on the student comments. All statistical tests were conducted where $p < .05$ was considered significant. All values were reported as a mean ± standard deviation.

Results

Participants

Of the 131 responses, 67 came from the pre-survey and 64 from the post-survey. As a whole, participants were mostly women (n = 101, 77.1%) and most commonly identified as White (n = 80, 61.1%) or Black/African American (n = 28, 21.3%). Race was dichotomized as white or minority (students reporting one or more minorities). Table 1 presents race and sex breakdown in the pre- and post-surveys.

Student Confidence with 3D Printing

Students in both courses reported increased confidence with the 3D printing process in the post- compared to the pre-survey, $F(1, 127) = 39.14$, $p < .001$, Cohen's $d = 1.09$ (Figure 2A). While students in Molecular Biology had marginally higher confidence overall, $F(1, 127) = 3.61$, $p = .06$, $d = 0.24$, the increase in confidence from pre- to post-test was the same for both courses, $F(1, 127) < 1$, $p > .05$, and also occurred in both white and minority women,

Table 1.

Participant Demographics

	Pre Survey		Post survey	
Race/ethnicity	**n**	**Percentage**	**N**	**percentage**
White	41	61.2	40	62.5
Minority	26	38.8	24	37.5
Sex				
Male	16	23.9	13	20.3
Female	50	74.6	51	79.7
Not answered	1	1.5	0	
Total	67		64	

ts > 4.37, ps <.001, ds > 1.47, (Figure 2B). There was no difference between white and minority women in this effect, F(1, 97) = 0.06, p = .80. This increase in confidence was specific to 3D printing; students didn't report significant changes in confidence with technology generally, all Fs < 1.27, ps > .26.

Student confidence with 3D printing

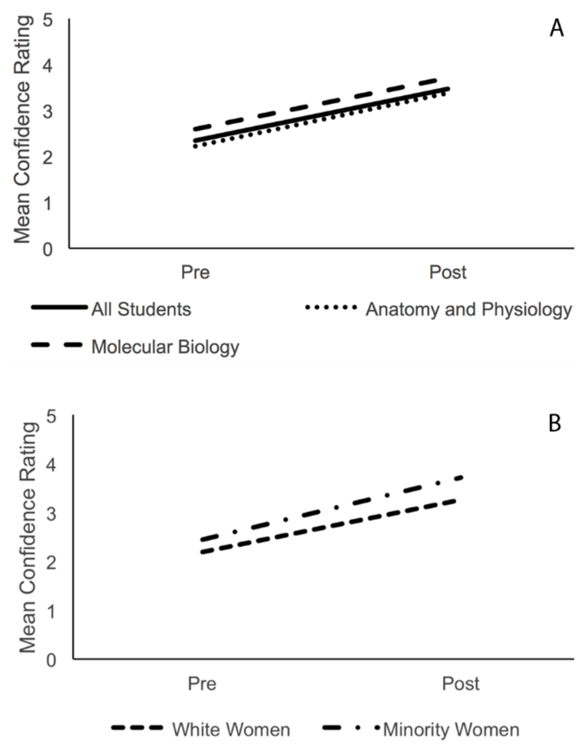
Student confidence with 3D printing increases with completion of a 3D printing project. (A) Students in both courses reported increased confidence in 3D printing, Fs > 3.60, ps < .06, ds > 0.23. (B) Minority women and white women reported significant gains in confidence, ts > 4.37, ps < .001, ds > 1.47; the magnitude was the same for both groups, F(1, 97) = 0.06, p = .80.

Student Attitudes towards 3D Printing in Biology Courses

Overall, students had high ratings for ease of use (3.70 + 0.84), value to learning (3.97 + 0.69), and believed that more courses should incorporate 3D printing technology (3.88+1.03; see Table 2). These ratings didn't differ by course (ts < 1.28, ps > .20). We then examined whether attitudes differed for underrepresented groups. Ratings were as high for women as for men (ts < 1, ps > .48) and were the same for white and minority students (ts < 1.26, ps > .21). Students rated the challenge of the 3D printing process as intermediate (2.63 + 1.02; see Table 2), and these ratings didn't differ based on race or gender (ts < 1.28, ps > .20). Students in Molecular Biology (3.24 + 1.30) rated the 3D printing process as more challenging than students in Anatomy and Physiology (2.40 + 0.80), t(62) = 3.08, p = .003, d = 0.87.

Figure 2.

Student confidence with 3D printing



Student confidence with 3D printing increases with completion of a 3D printing project. (A) Students in both courses reported increased confidence in 3D printing, *Fs* > 3.60, *ps* < .06, *ds* > 0.23. (B) Minority women and white women reported significant gains in confidence, *ts* > 4.37, *ps* < .001, *ds* > 1.47; the magnitude was the same for both groups, *F*(1, 97) = 0.06, *p* = .80.

Table 2.

Likert scale responses to 3D Printing.

	Ease of Use and Usefulness of 3D Technology		Value to Learning		Include 3D Printing in More Courses		Challenging	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
All students	3.70	0.84	3.97	0.69	3.88	1.03	2.63	1.02
Course								
Molecular Biology	3.88	1.04	4.15	0.81	4.00	1.12	3.24	1.30
Anatomy and Physiology	3.64	0.76	3.90	0.63	3.83	1.01	2.40	0.80
Sex								
Male	3.65	1.09	3.94	0.89	3.69	1.25	2.31	1.03
Female	3.72	0.78	3.98	0.64	3.92	0.98	2.71	1.01
Race/Ethnicity								
White	3.65	0.83	3.90	0.65	3.75	1.01	2.75	1.03
Minority	3.79	0.87	4.09	0.75	4.08	1.06	2.42	0.97

Note. 1 = *Strongly Disagree*, 2 = *Agree*, 3 = *Neither Agree nor Disagree*, 4 = *Agree*, 5 = *Strongly Agree*

Student Responses to Open-Ended Questions

Students made overwhelmingly positive comments, and the tone of the comments was the same at the beginning and end of the term, $\chi2(2, N = 109) = 1.48$, $p = .48$ (Table 3). General interest or excitement about 3D printing was the most common theme mentioned by students. Only references to having or lacking prior experience with 3D printing were more frequent at the beginning of the semester relative to the end of the semester; all other comments occurred in similar proportions at both times,

$\chi2(3, N = 187) = 8.47$, $p = .04$, which was a small effect, Cramer's $V = .21$.

Discussion

This study examined student perception of the inclusion of a 3D printing project in Anatomy and Physiology and Molecular Biology courses at a public primarily undergraduate institution. Students in both courses reported a large increase in confidence with 3D printing after completing the project, and this increase in confidence was demonstrated in both underrepresented minority women and white women. Additionally, students indicated that the 3D printing project added high value to learning, was generally easy to use, and should be incorporated into more courses. Students also reported overwhelmingly positive comments about 3D printing, with general interest or excitement reported the most frequently.

Comparisons made between Anatomy and Physiology and Molecular Biology courses demonstrated marginal differences. Molecular Biology students had a slightly greater increase in confidence with 3D printing and rated the 3D printing process as more challenging compared to Anatomy and Physiology students, which is not surprising considering the differences in the 3D printing projects between the classes. Molecular Biology students had a longer 3D printing workflow and worked individually, while Anatomy and Physiology students had a shorter 3D printing workflow and shared responsibilities between group members. Differences between these courses may also be related to the target student population, as Anatomy and Physiology students included non-Biology majors and primarily underclassmen, while Molecular Biology students included junior and senior Biology and Biochemistry majors, as well as Biology Masters students.

As noted in previous studies in Anatomy and Physiology, one of the advantages in utilizing 3D printing technology is the ability to create models that may not otherwise be available or may be costly (AbouHashem et al., 2015; Thomas et al., 2016). Similarly, in our study, students were able to print anatomical models that are not typically available in an undergraduate lab, such as the subcortical brain structures model. Likewise, in Molecular Biology, the models our students printed that were connected to their review paper cannot be purchased. This creates

Table 3.

Qualitative responses to 3D Printing.

Comment Characteristic	Pre (*N* = 57) *n*	%	Post (*N* = 52) *n*	%	*Sample Comments*
Tone					
Positive	49	86.0	41	78.9	"I am interested and excited to use 3D printing technology."
Neutral	3	5.3	6	11.5	"It was something new and different."
Negative	0	0	0	0	
Mixed	5	8.8	5	9.6	"I do not feel strongly about 3D printing, however it does seem like something that could be interesting but also intimidating as it is something I have not done before."
Theme					
General interest or excitement	49	86.0	46	88.5	"I think this will be a very cool experience."
Understanding concepts or how to use technology	16	28.1	22	42.3	"3D printing is relatively simple, but it is a hassle having to have so many different programs to complete the work. The post-processing of taking off the base and supports is more simple and fun than it appears."
Applying 3D printing to a course or profession/medicine	15	26.3	24	46.2	"3D printing is very useful in many aspects of the world. The main area that I have heard of 3D printing being used is in the medical field."
Prior experience with 3D printing	12	21.1	3	5.8	"it was something new and different."

Note. Each comment was evaluated separately for tone and for themes. Tone categories were mutually exclusive, but a comment could contain multiple themes.

a unique opportunity for students to create models that not only benefit their individual learning experience, but also add to the lab/course collection of resources that will enhance learning for future classes.

Increased confidence after completion of the 3D printing project reported by minority and white female students is a significant finding and has broader implications for retaining women in STEM programs. Previous research has found that women generally perceive themselves as academically weaker compared to men, including lower confidence in their academic abilities, even though they perform similarly to their male counterparts when their academic skills are tested objectively (MacPhee et al., 2013). The long-lasting repercussions surrounding academic self-efficacy may include leaving STEM programs and lack of entry into STEM careers (MacPhee et al., 2013). Our findings of improved self-efficacy by actively engaging with new technology in the classroom are encouraging and this was noted by female student comments in our surveys, particularly as it relates to visual-spatial perception:

> "This was a great opportunity to see smaller creations come to life. I really enjoyed finding a model, picking it out and being able to see a smaller replica of what I chose. I believe this a great advancement towards technology, research, and future medical breakthroughs."

> "I think that 3D printing is a great resource, especially for STEM classes, in that you can see and manipulate the object that you are trying to study. This project was very helpful, and I think it is a great project to continue in other classes."

Future Directions

The focus of this study was to examine student perceptions surrounding their 3D printing experience; therefore, we did not quantify the effectiveness of our 3D printing projects on student learning through objective assessments such as exams or quizzes. Future research will examine how 3D printing impacts learning gains through controlled assessments of relevant course concepts and content.

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Appendix

APPENDIX A: QUALTRICS PRE-SURVEY

PLEASE ANSWER THE FOLLOWING QUESTIONS.

1. Student Code (as provided by the instructor):_____________

2. Which course are you taking?
   a. Molecular Biology
   b. Anatomy and Physiology
   c. Cell Biology

3. Do you have any experience with 3D printing?
   a. Yes
   b. No

4. Are you aware that Winthrop has 3D printing facilities available on campus?
   a. Yes
   b. No

5. How confident are you with using 3D printing?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

6. How confident are you with using technology in general?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

7. How interested are you in using 3D printing?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

8. How interested are you in using technology in general?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

9. Please describe your attitude towards 3D printing.

Demographic Information

1. What is your current age?

2. What is your sex?
    a. Male
    b. Female
    c. Prefer to self-describe:____________
    d. Prefer not to answer

3. Please select all racial and ethnic groups with which you identify.
    a. American Indian or Alaska Native
    b. Hispanic, Latino, or Spanish origin
    c. White
    d. Asian
    e. Middle Eastern or North African
    f. Black or African American
    g. Native Hawaiian or Other Pacific Islander
    h. Another race or ethnicity not listed above, please specify:
    i. Prefer not to answer

4. What is your current overall GPA at Winthrop?
    a. 3.5-4.0
    b. 3.0-3.49
    c. 2.5-2.99
    d. 2.0-2.49
    e. Below 2.0
    f. Prefer not to answer
    g. Unsure

APPENDIX B: QUALTRICS POST-SURVEY

PLEASE ANSWER THE FOLLOWING QUESTIONS.

1. Student Code (as provided by the instructor):_____________

2. Which course did you take?
   a. Molecular Biology
   b. Anatomy and Physiology
   c. Cell Biology

3. Did you have any experience with 3D printing before this course?
   a. Yes
   b. No

4. Were you aware that Winthrop has 3D printing facilities available on campus before this course?
   a. Yes
   b. No

5. How confident are you with using 3D printing?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

6. How confident are you with using technology in general?
   a. Very confident
   b. Confident
   c. Neither confident nor unconfident
   d. Unconfident
   e. Very unconfident

7. How interested are you in using 3D printing?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

8. How interested are you in using technology in general?
   a. Very interested
   b. Interested
   c. Neither interested nor uninterested
   d. Uninterested
   e. Very uninterested

9. Please describe your attitude towards 3D printing.

PLEASE SELECT ONE OF THE FOLLOWING FOR EACH ITEM BELOW.

1	2	3	4	5
STRONGLY DISAGREE	**DISAGREE**	**NEITHER AGREE NOR DISAGREE**	**AGREE**	**STRONGLY AGREE**

Ease of use/usefulness

2. The 3D printer was easy to use.
5. Using current technology, like 3D printing, will benefit me in my future career or educational goals.

Learning value

1. The 3D printed model helped me better understand course concepts.
3. The 3D printed model did not improve my learning experience.*
6. It was easier to visualize abstract course concepts using the 3D printed model.
8. The 3D printed model helped me better understand student presentations.
9. I learn better when a 3D printed model is available.
10. The 3D printing assignment added value to this course

Desire to have 3D technology in more courses

4. I would like more courses to incorporate 3D printing.

How challenging

7. The 3D printing process was challenging.

** Reverse-scored items*

DEMOGRPAHIC INFORMATION

1. What is your current age?

2. What is your sex?
    a. Male
    b. Female
    c. Prefer to self-describe:_________________
    d. Prefer not to answer

3. Please select all racial and ethnic groups with which you identify.
    a. American Indian or Alaska Native
    b. Hispanic, Latino, or Spanish origin
    c. White
    d. Asian
    e. Middle Eastern or North African
    f. Black or African American
    g. Native Hawaiian or Other Pacific Islander
    h. Another race or ethnicity not listed above, please specify:
    i. Prefer not to answer

4. What is your current overall GPA at Winthrop?
    a. 3.5-4.0
    b. 3.0-3.49
    c. 2.5-2.99
    d. 2.0-2.49
    e. Below 2.0
    f. Prefer not to answer
    g. Unsure

5. What is your current grade in this course?
    a. 90-100
    b. 80-89
    c. 70-79
    d. 60-69
    e. Below 60
    f. Prefer not to answer
    g. Unsure

APPENDIX C: ANATOMY AND PHYSIOLOGY PROJECT DESCRIPTION AND GRADING RUBRIC

Project Overview

Students will work in groups of 4, selected by the instructor. Each group will select an organ to be 3D printed and that organ will serve as the foundation for an oral presentation due at the end of the semester. The purpose of this project is to utilize current technology (3D printing), apply it to anatomical use, connect organs with their systems, and relate this to a clinical disorder. Students will also improve technical communication skills through an oral presentation and interpersonal skills through group work.

Project Details

1) Students will select an organ covered in BIOL 214 to 3D print using the following website options: www.thingiverse.com, https://www.embodi3d.com, or https://3dprint.nih.gov. Students will edit the design, select printing materials, and ensure correct printing of the organ. Further instructions on 3D printing will be provided.

2) Students will outline how this organ fits into the organ system and connect this with a clinical disorder. For example, the kidney belongs to the urinary system, which is composed of the kidneys, urinary bladder, ureters, and urethra. A detailed description of key anatomical features of the organ will be provided by the students and the 3D printed version will be analyzed to determine accuracy of the printing process. Please note, the 3D printed version may not be completely accurate. Students will not be penalized if this is the case, however, the students should be able to discuss the inaccuracies in their presentation.

3) Students will select a clinical disorder related to this organ and present the key causes, symptoms, diagnosis, and treatment.

4) Students will present their findings to the class in a 10-minute oral presentation. All students are expected to speak during the oral presentation. During this presentation, students must use their 3D printed model as a visual aid to explain their clinical disorder. For example, if students choose to discuss kidney stones, the model could be used to demonstrate the location of the stones and how the kidney is treated to eliminate kidney stones. Students will likely need to supplement the model with other visual aids (for example, bringing in something to represent the kidney stones).

5) Students will evaluate their peer’s presentations and provide feedback. Students will also provide feedback on their team member’s participation and effort.

Grading Rubric

This project is worth 50 total points and will count as 50 out of the 100 points on the final exam. The 3D printed organ and completed PowerPoint presentation is due on August 2, 2019.

Project Item	0 Points	5 Points	10 Points
3D printed organ	Organ is not turned in.	Organ is turned in, but there are significant errors with printing due to incorrect selection of printing materials.	Organ is turned in and complete.
Oral presentation: organ anatomy	No description of organ anatomy included in oral presentation.	Partial description of organ anatomy in each category or entire categories are missing in oral presentation.	Complete and accurate description of organ anatomy, connection to organ system, and asessment of 3D model accuracy included in oral presentation.
Oral presentation: clinical disorder	No description of clinical disorder included in oral presentation.	Partial description of clinical disorder in each category or entire categories are missing in oral presentation.	Complete description of clinical disorder including key causes, symptoms, diagnosis, and treatment. Accurately relates to selected organ.
Oral presentation: use of 3D model to explain clinical disorder	3D model is not included in oral presentation.	3D model is included in oral presentation, but there are inaccuracies in its use.	3D model is appropriately included in oral presentation and helps clarify the clinical disorder.

Project Item	0 Points	2.5 Points	5 Points
Oral presentation: organization and clarity	Oral presentation is confusing and only one student presents.	Oral presentation is organized, but not all students present or some students present very little.	Oral presentation is well organized and all students present proportionally.
Peer and team evaluations	Student did not complete peer or team evaluations. Student did not participate in project based on feedback from peers and/or team.	Student is missing either peer or team evaluations. Student participation was minimal in project based on feedback from peers and/or team.	Student completed both peer and team evaluations. Student fully participated in project based on feedback from peers and team.

Project Item	Points Received	Total Points Possible
3D printed organ		10
Oral presentation: organ anatomy		10
Oral presentation: clinical disorder		10
Oral presentation: use of 3D model		10
Oral presentation: organization and clarity		5
Peer and team evaluations		5

TOTAL SCORE = ______out of 50.

APPENDIX D: MOLECULAR BIOLOGY PROJECT DESCRIPTION AND GRADING RUBRIC

PROJECT OVERVIEW

The purpose of this project is to learn and utilize current 3D printing technology, apply 3D printing to the study of molecular biology, and use a 3D printed object to help communicate current research in molecular biology. This project ties into the review paper and presentation assignment for this course. You must produce a 3D-printed object that is related to your review paper on current research within the field of molecular biology, and you must effectively incorporate the object into your presentation.

PROJECT DETAILS

1) Students will create or find an object/file related to their review paper to 3D print. The following websites are good resources to start with: www.thingiverse.com, https://3dprint.nih.gov, or https://www.embodi3d.com.
2) Students will edit the design and/or printing parameters as necessary, select printing materials, and ensure correct printing of the organ in collaboration with the Winthrop University Creator Space. Please note, the 3D printed version may not be completely accurate. Students will not be penalized if this is the case; however, students should be able to discuss the inaccuracies in their presentation. Further instructions on the 3D printing process will be provided.
3) During the presentation of the review paper, students will explain how their 3D printed object connects to molecular biology and is relevant to their paper. The object will be used to communicate key elements of the review paper.
4) Students will complete the 3D printing project worksheet.
5) Students will evaluate their peers' presentations and provide feedback.

GRADING RUBRIC FOR 3D PRINTING PROJECT

This project is worth 50 total points. **The 3D printed object is due on the day of the student's presentation.**

10 Point Project Items	0 Points	5 Points	10 Points
3D printed object	Object is not turned in.	Object is turned in, but there are significant errors with printing due to preventable student error.	Object is turned in and complete.
Connection of 3D printed object to molcular biology explained in presentation	Object is not connected to molecular biology.	Connection of object to molecular biology exists but is not well explained.	Connection of object to molecular biology is clear and well explained.
Relevance of 3D printed object to review paper explained in presentation	Object is not relevant to review paper.	Object is relevant to review paper but relevance is not well explained.	Object is relevant to review paper and relevance is clear and well explained.
Oral presentation: Utilization and integration of 3D printed object	Object is not discussed in oral presentation.	Object is utilized and/or integrated ineffectively in presentation.	Object is utilized and integrated effectively in presentation.
5 Point Project Items	**0 points**	**2.5 points**	**5 points**
3D printing project worksheet	Worksheet is not completed.	Worksheet is partially completed or completed poorly.	Worksheet is fully and well completed.
Peer evaluations	Does not meet requirements	Meets most or all requirements	Meets all requirements and is well-delivered

Project Item	Points Received	Total Points Possible
3D printed object		**10**
Connection to molecular biology in presentation		**10**
Connection to review paper in presentation		**10**
Utilization in oral presentation		**10**
Worksheet		**5**
Peer Evaluations		**5**

TOTAL SCORE = ______out of 50.

APPENDIX E: MOLECULAR BIOLOGY 3D PRINTING PROJECT WORKSHEET
Answers must be typed.

1. **Describe how you found/created the file you 3D printed. Include a description of any editing or modifications that were made prior to printing.**
2. **Which printer and material did you use to print your object and why?**
3. **Explain how the printer that you used works.**
4. **What was the cost of printing your object?**
5. **What post-processing was required for your object?**
6. **Explain how your object is related to molecular biology.**
7. **Explain how your object is related to your review paper.**

DNA Fingerprinting of *Brassica Rapa* Using SRAP—Sequence-Related Amplified Polymorphism DNA Fingerprinting: An Experiment for use in a College Biology Course

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Abstract

We used a novel approach that combined direct PCR of plant tissue and SRAP DNA fingerprinting to seek to identify the crosses made in *Brassica rapa* used in the Wisconsin Fast Plants. Our goal was to develop a rapid method for students to use in a biology, botany, or genetics class to identify the parental types (purple stem, non-purple stem) and the F1 generation for *Brassica rapa*. Our data indicates that there is detectable polymorphism in the *Brassica Rapa* plants with which to identify the three types of plants.

Introduction

We continually look for new experiments that offers our students a "taste" of exploration of the real world, allow them to become familiar with biotechnology tools, and capture their attention, setting them on a path of discovery in our amazing world. The basis for this experiment is to have students identify the first filial generation (F1) plants from the parental types by screening for genetic variations between the three.

SRAP uses primer pairs in PCR. By using a forward and reverse primer pairs that are 17 or 18 nucleotides long, SRAP can amplify open reading frames and test for the presence of polymorphism, or variations in the nucleotide sequences. This method is simpler and overcomes several problems with other PCR marker systems used to create genetic maps of plant species. Primers were originally created by Li and Quiros using the strategy of filler sequence, an open reading frame (ORF) region, and a selective, sequence. Starting at the 5' end of the forward primer bases 1-10 are filler and nonspecific; bases 11-14 are specific and use CCGG which targets exons in the plant chromosome; and bases 15-17 are selective. For the reverse primer bases 1-10 are filler (different than the forward primer filler); bases 11-14 are specific and use AATT which targets introns and promotor in the plant chromosome; and bases 15-17 are selective (Li and Quiros). These primers enable the system to detect polymorphisms.

This method can be applied to a rapid cycling version of *Brassica rapa*. Carolina Biological Supply company and University of Wisconsin-Madison teamed up to market a fast growing plant for use in the educational classroom. They call their system Wisconsin Fast Plants. These rapid-cycling brassicas were developed over a 15 year period by Professor Paul H. Williams. *B. rapa* plants are related to mustards and cabbages. The rapid-cycling brassicas are an excellent tool for classrooms because they take up little space, 2500 plants per square meter, grow from seed to flower in 18 days, and produce seed by day 28. All of this is accomplished using fluorescent lighting (Williams, P.H.).

With the addition of rapid-cycling brassicas to our lab we felt we could develop a simple system whereby students could identify *B. rapa* plants with different traits. In fact, the goal was to find polymorphisms that would distinguish the two true-breeding *B. rapa* parents from their subsequent F1 offspring. To test this idea we recruited three of our biology students to test this project.

Results

Using primer pair combinations (Me1/Em1, Me4/Em1, Me4/Em3, Me4/Em6, Me5/Em6) the parental purple stem, parental non-purple stem and F1 purple stem plants were tested for polymorphisms. With the Wisconsin Fast plants we were able to get numerous bands, representing polymorphisms, from each of the three plants tested. Figures 1, 2, and 3 are DNA gels that show the banding patterns for each plant. Because we did not target one specific gene the F1 purple plant is not exactly the same banding pattern as the purple parent. This is reasonable because other genes were inherited from both parents.

Primer pairs that worked well and gain different banding patterns for all three samples were Me1/Em1, Me4/Em1, Me5/Em6, and Me4/Em6. Me4/Em3 was a smear on the two parents (probably degraded DNA) and good bands on the F1 plant. In figures 1, 2, & 3 the banding patterns in the red box indicate polymorphisms for all three plant sample and are the best to use in a classroom setting.

Figure 1

Parental type (Purple Stem) SRAP PCR products using different primer pairs for the Purple Stem parent plant

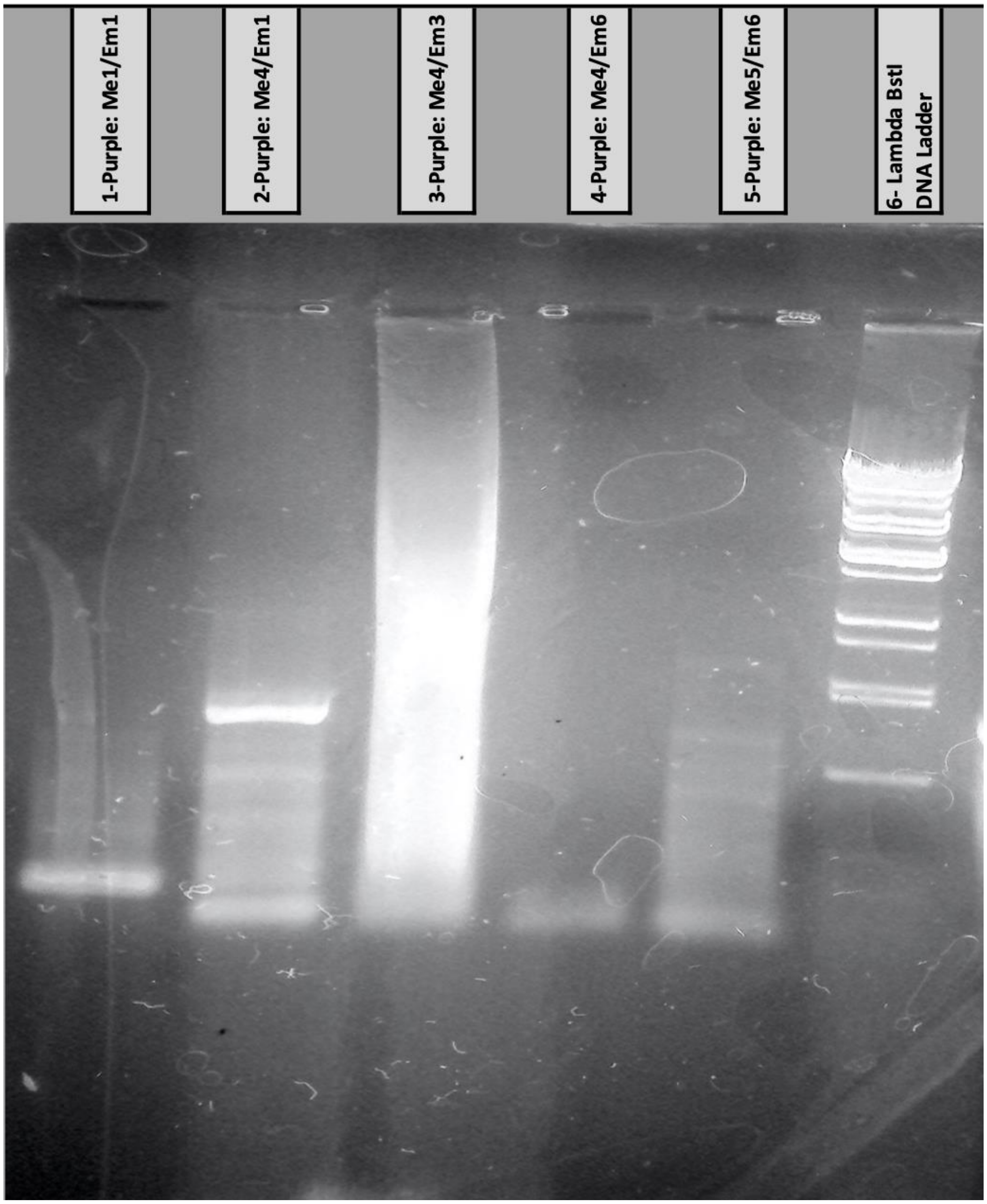


Figure 2

Parental type (Non-Purple Stem) SRAP PCR products using different primer pairs for the Non-Purple Stem parent plant

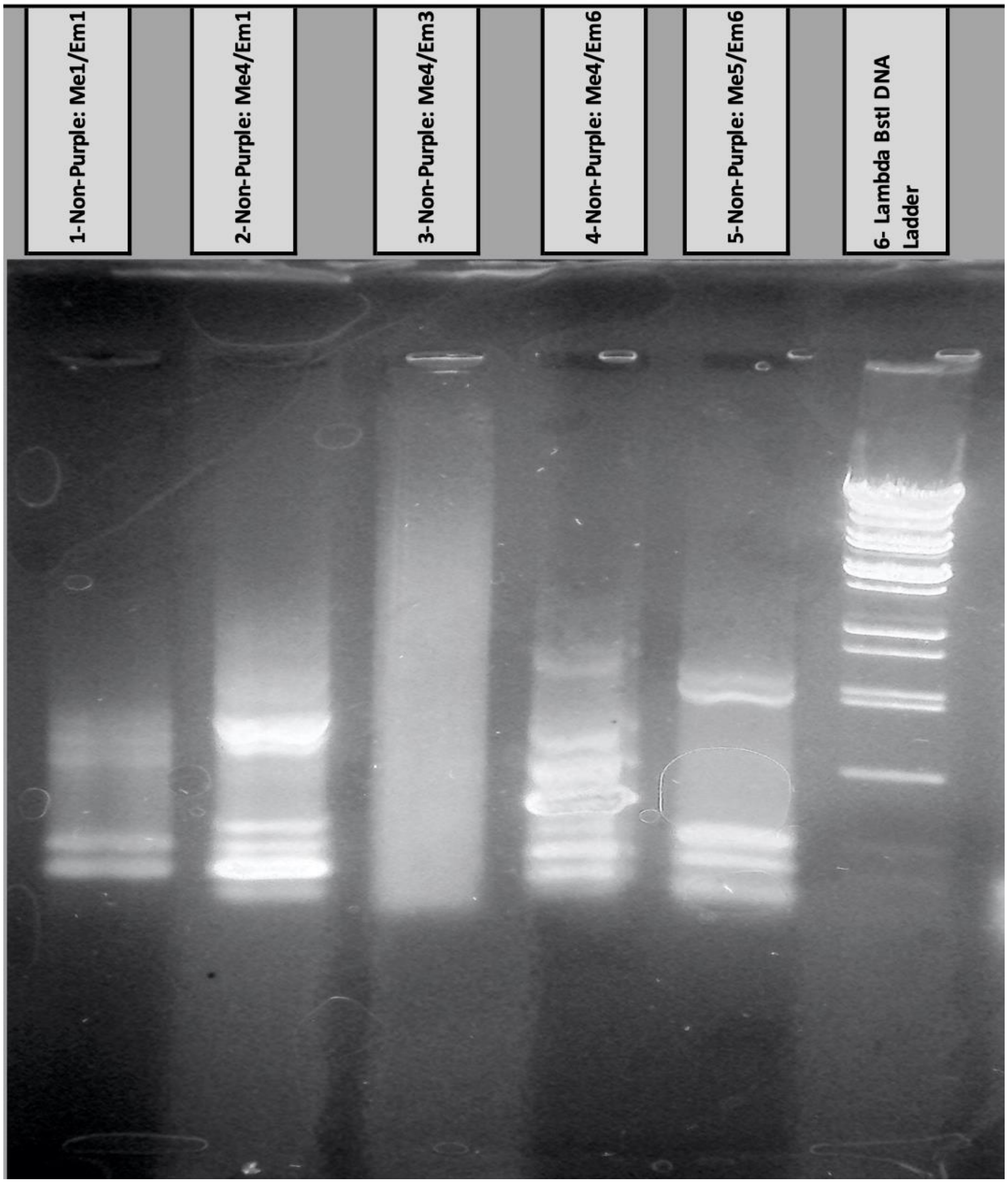
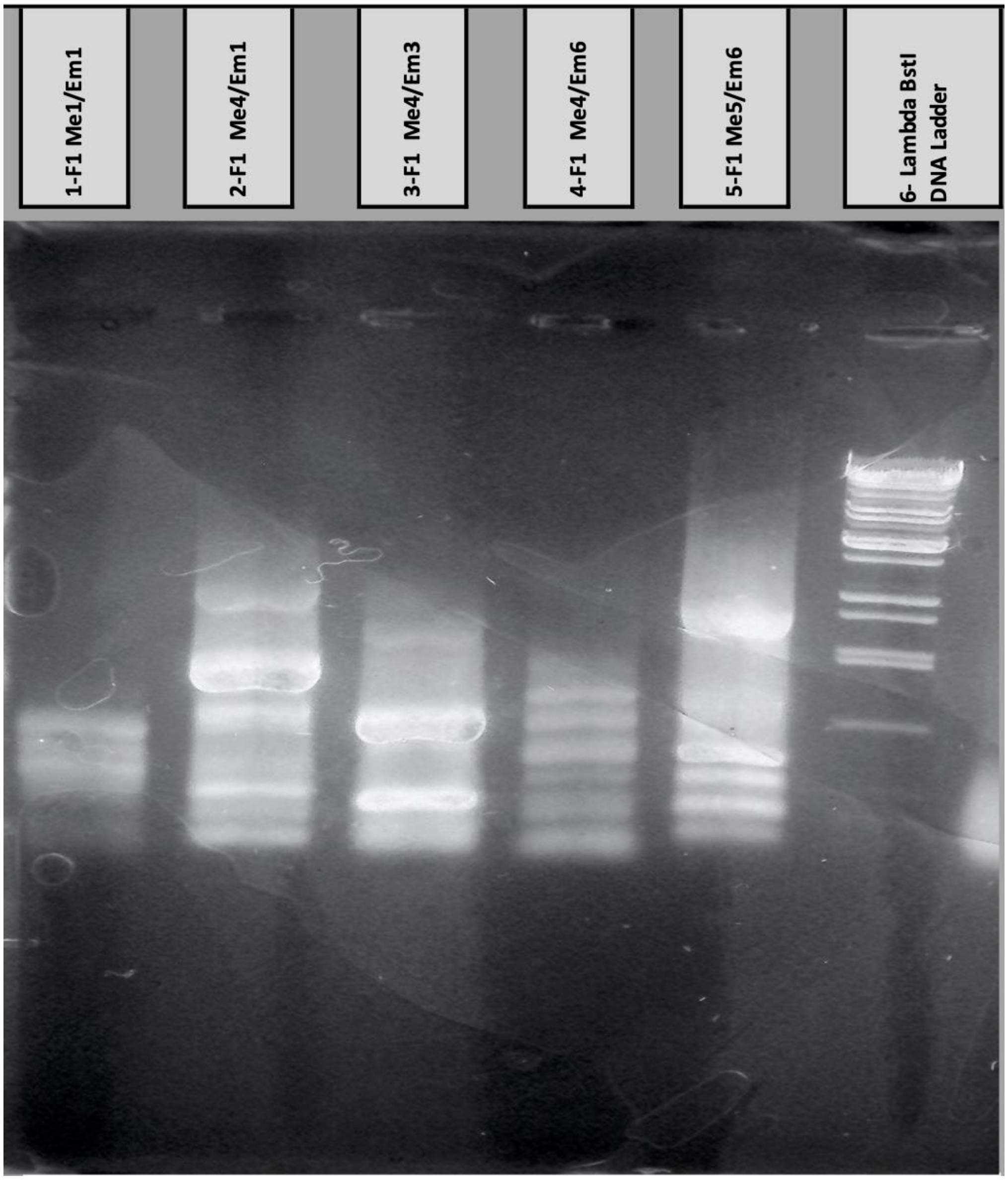


Figure 3

First filial generation (F1) SRAP PCR products (Parents-Purple vs Non-Purple) using different primer



Discussion

Three students tested the system, and the results indicate this system works for differentiating the parental and F1 Wisconsin Fast Plants. The experiment is very easy to do. Students could be given a tube of the PCR master mix to which they will add a leaf sample. From there it will go into a thermocycler so that it will be ready to run on gel electrophoresis the next day or next class. Gels can be premade for the students or students can make their own if the instructor is comfortable with the addition of ethidium bromide (a mutagen). Subsequently, our lab has switched from ethidium bromide to a non-toxic stain called Gel Green Nucleic Acid Gel Stain from Minipcr.com. We run mini-gels which takes about an hour after which it is ready to view on the UV transilluminator. All in all this experiment can be completed over two lab days once the Wisconsin Fast plants have germinated for a minimum of three days.

Methods

Plant Material

From each plant a 1mm piece of leaf was excised just prior to the experiment. Fast-cycling brassicas were planted from seed using Parental types of Purple Stem (dominant) and a mutant non-purple stem (recessive). The F1 plant was a cross between two parental types and yielded the dominant phenotype of purple stem. The Fast-cycling brassica seeds were purchased from Carolina Biological Supply, Burlington, North Carolina.

Protocol for the SRAP Marker System

Primer pairs were selected from the methods of Li and Quiros. The following primers were ordered from Operon Technologic Inc., Alameda, CA:

Sequence (5'—3')

- Me1 (forward)—TGAGTCCAAA CCGG ATA
- Me4 (forward)—TGAGTCCAAA CCGG TAG
- Me5 (forward)—TGAGTCCAAA CCGG TGT
- Em1 (reverse)—GACTGCGTACG AATT TGC
- Em3 (reverse)---GACTGCGTACG AATT AGC
- Em6 (reverse)---GACTGCGTACG AATT AAT

DNA Amplification

DNA amplification was completed using Terra PCR Direct Polymerase Mix from Clonetech, Mountain View, CA

A 1mm piece of fresh plant leaf was added directly to the Terra PCR Direct Polymerase Mix per Table 1 (3). We followed the thermocycler settings used by Li, Y, Fan, X., Shi, T., Zhang, Q., & Zhang, Z as follows: One cycle at 94 C for five minutes, five cycles at 94 C for one minute, 35 C for one minute, and 72 C for one minute, then thirty-five to forty cycles at 94 C for one minute, 50 C for one minute, and 72 C for 1 minute. PCR ended with one cycle at 72 C for five minute and then held at 4 C.

Table 1.

Recipe list to make the master mix for Terra PCR Direct (4*)*

Table I: Recommended Master Mix		
Reagent	**Volume**	**Final Conc.**
2X Terra PCR Direct Buffer (with Mg^{2+}, dNTP)	25 μl	1X[a]
Primer 1	15 pmol	0.3 μM
Primer 2	15 pmol	0.3 μM
Tissue Sample/Extract	$\leq 5\ \mu l$[b]	
Terra PCR Direct Polymerase Mix	1 μl	1.25 U
Sterile Water	up to 50 ul	
Total Volume per reaction	50.0 μl[c]	

Gel Electrophoresis

DNA from PCR was separated by size on a 1% agarose gel and visualized using 1ul of 10mg/ml stock of ethidium bromide added to the gel while still molten and allowed to solidify.

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Innovations

Foldscope™ as a Teaching and Learning Tool: An Indian Perspective

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Abstract

Science is all about how and why. India is a land of diversity and having an equally diverse education system. In a diverse classroom, it is important for the teacher to impart knowledge in such a way that it kindles curiosity in the learner. The best way to communicate science is 'learning by doing'. This requires great skill and apt teaching methodology especially in non-urban areas where the learning resources are scarce. In this regard there is a dire need for inexpensive, useful teaching and learning tools that can foster interest in science. This article is concerned with exploring the use and application of one such innovative tool—Foldscope™. Foldscope™ is a low cost, paper microscope that can help to magnify beyond the ability of unaided eye and explore our surroundings at the microscopic level. It is well suited to be used as a teaching and learning aide in Under-resourced regions. During the pandemic COVID-19 online and distance mode learning has come as a savior, this frugal tool can further facilitate practical learning because of its portability and unique features.

KeyWords: Foldscope, Teaching-Learning Process (TLP), Teaching tool, Portable microscope, Magnetic coupler, On-site foldscopy

Introduction

India, a country in South-Asia, is a myriad of geographical demographics with multitude of ethnic, linguistic and cultural diversity. Its unique diversity is the strength and basis of modern India. India was once a powerhouse of knowledge and wisdom. Despite a strong heritage of intellectuals and their pioneering contribution to the world in education and other fields, the present scenario of education needs innovative changes to foster creative and critical thinking skills.

Present Scenario of Education in India

The model curriculum formulated by Kothari Commission as per *Report of Ed. Comm, 1971*(Aggarwal, 2009) set up to maintain uniformity has not yet fulfilled its objective. The present educational system in India is more of an input/output kind of model. Due to an Examination-centric education system that promotes rote learning, students face a highly stressful environment with multifaceted competitions. A fierce battle is seen for grabbing grades focusing more on earning a degree and less on real skills.

The scenario of science education is even more complex, as it has failed to inculcate creativity and innovation among learners. It is a general perception that teaching science involves huge investment and that in a developing country where resources are limited, teaching modalities need to be limited (Kremer et al., 2013). Physical infrastructure in Indian institutions varies due to geographical and financial disparity. The conventional approach of knowledge dissemination using the chalk, talk, and walk method is practiced predominantly. Information and communications technology (ICT) teaching aides such as computers and LCD projectors are beyond the reach of many institutes and science laboratories, still a dream in remote areas.

In the era of globalization, Teaching-Learning Process (TLP) needs transformation (Mohapatra et al., 2012).The two crucial components–the teacher and learner both-- are continuously evolving with the changing educational needs. TLP is directed by quality of learning rather than teaching. For in-depth understanding of scientific concepts and phenomena, engaging students in practical activities is an important part of active learning in science education

(Nawani & Jain, 2010). Field-based study is critical to teaching and learning biology and can lead the students to discovery-based learning (Wieman & Gilbert, 2015; Fleischner et al., 2017).

The Digital India initiative aimed at empowering youth has led to increase in the use of laptops and tablets as a part of TLP. To meet the challenges thrown by learners, techno savvy gadgets that can be carried in pockets have conceived the recent ‘anytime, anywhere’ learning concept (Smith et al., 2011). One such tool that helps in ‘active learning’ is Foldscope™ (Cybulski et al., 2014). It is a cheap and portable paper microscope.

Though journey of microscope started around 300 years ago since the time discovered by Leeuwenhoek (Wollman et al., 2015), but is ever evolving in many ways. It is still out of the reach of many, and finds its place in laboratories only. Learning and understanding science is not a privilege of a few who can afford resources. The lesser privileged students from rural and tribal areas, where infrastructure is negligible and they have rarely been exposed to microscopes in their learning years, this affordable paper microscope-Foldscope™ is a hope for the less privileged to learn. The present article is based upon this innovative tool— Foldscope™ and its possible explorations in microscopic world within and beyond boundaries of class room. While there have been many publications over the past decade reporting on portable or mobile-phone microscopes, like Cellscope™ (Philips et al., 2015), comparably few studies have been reported of using it under field conditions. The COVID-19 pandemic has led to digital transformation of education even in most deprived regions of the nation and online teaching and distance education has come as a solution. This cheap tool can further facilitate practical learning of biology, as it has the potential to conform to curiosity of the learners due to its ease of use, low cost, and portability.

Democratization of Science: A Govt. of India initiative

Foldscopy is an initiative of DBT, GoI (Department of Biotechnology, Govt. of India) for augmenting science education. DBT aims at *Popularization and Democratization of Science* in India by taking science to the doorsteps of all, even in resource poor settings across the country. With this objective DBT has partnered with Prakash lab’s on foldscopy to make the mission ‘Science for all’ possible. As a part of this endeavor the department has sanctioned projects grants to researchers and academicians in schools and colleges for exploring diverse habitats. Twining Programme is initiated by DBT (GoI) to booster the collaboration of North Eastern states with other parts of India for quality research, education and training in biosciences (Sharma and Mohan, 2016). Under its Foldscope™ Twining programme, collaborative research projects between North Eastern Region (NER) institutions and from other parts of country has culminated exchange of innovative ideas among different Foldscope users across the nation. (http://dbtindia.gov.in).

Foldscope™: The portable microscope

An Overview

Foldscope™ is a low-cost, thin, pocket microscope made of color-coded paper coated with water-proof polymer. Manu Prakash, the brain behind this tiny invention, an Indian-origin scientist at Stanford University, conceptualized the idea, keeping in mind the resource constraints of developing countries (https://foldscope.com).

Foldscope™ works on the same principle of magnification as a simple microscope. It is a transmissive light microscope. The low power lens supplied with the kit is a borosilicate glass ball embedded in a circular black plastic piece; it is capable of magnifying objects 140X. This magnification is highly effective if compared to a low power lens of a compound microscope used in laboratories which has a 4X objective lens and a 10X eyepiece, the magnification being only 40X (Cybulski et al., 2014).

Unique Features

Foldscope™-the origami-based mini-microscope has following features:

- It can be assembled from a waterproof flat sheet of paper containing its jigsaw pieces within 10-15 minutes.
- Its tiny size ensures safety against damage even if dropped from a multi-storied building or stepped on.
- It is portable - being small, it can easily fit in a pocket.
- It does not require an external power source for illumination.
- It can be used for direct viewing by eye or can be projected on a screen.
- It can be coupled to a mobile phone to capture images.
- It can be used for bright-field, fluorescence or projection microscopy.

Basic Foldscope™ kit and its variants

Components included in basic individual Foldscope kit are enough to observe microscopic specimens around us. It contains Foldscope™, prepared glass slides, standard paper slides, microwell paper slide, an extra magnetic coupler, ring stickers, cover slip stickers and a cotton swab. Another variant, "The deluxe individual kit" is supplied with versatile accessories, it includes an LED magnifier light, scissors, forceps, microwell plates, petridish, microfuge tubes, droppers, strainer, clear tape roll, microscope slide set, reusable slides and cover slips, ring stickers, sterilized sample bags, a notebook and a pencil. The Foldscope™ instrument is identical in all the variants.

How to use

Foldscope™ is ready to use in three easy steps (Fig.1).

- The first involves assembling the Foldscope™ unit by joining together different pieces from a flat sheet provided in the Foldscope™ kit
- The second focuses on collecting and working with the samples.
- The third captures images of the object using smart phone coupled to Foldscope™ with a magnetic coupler (http://www.foldscope.com).

Figure 1 *Steps to use a Foldscope™*

A) Color coded waterproof origami sheet. B-C) Jigsaw pieces taken out from sheet which are joined together by paper folding to assemble Foldscope. C) Various accessories and kit components of Foldscope kit which are used for sample collection, preparation and viewing. D) Front view of Foldscope instrument-blue in color. E) Rear view of Foldscope instrument- yellow in color having slide pocket where slide is inserted upside down. F) Foldscope attached to smart phone. *Courtesy: Foldscope instruments*

Sample Preparation and viewing

Specific directions to use are provided in detail with each Foldscope™ (http://www.foldscope.com). It allows any curious explorer to have microscopic observation of any sample within short time with just a simple glass slide, transparent tape or cover slip and Foldscope™ without requiring any costly material or equipment.

Sample

Sampling involves mounting a small piece of the specimen on a glass slide and covering it either with a glass cover-slip or fixed using a piece of clear transparent tape/adhesive. Enormous variety of samples, dry or wet, can be observed under Foldscope™. It can be tiny microorganisms like some filamentous bacteria, fungi, protozoa, various tissues and cells for histological studies, as well as large organisms like nematodes, insects and their larvae, pollen grains, feathers, etc. Any translucent sample that allows the light to pass through it can be viewed under Foldscope™. Very dense and thick samples can be spread in a suitable liquid and covered with the cover slip. Simple staining techniques are required for better visualization of certain samples, while some can be viewed directly. Dry mounts are ideal for observing hair, feathers, airborne particles such as pollens and dust, as well as dead matter such as insect legs or antennae. Opaque specimens require very fine slices for adequate illumination.

Slide insertion and focusing

The slide is inserted within the slide pocket upside down (towards yellow side). Focusing of the mounted object can be adjusted in a simple way by sliding the paper platform with the thumb and forefinger.

Viewing

There are three methods to view the samples. First, the sample can be viewed directly through the eyes (Fig. 1). Second, it can be viewed through the camera of mobile phones. To view a sample with a phone, attach a magnetic coupler (provided in kit) over the lens of your phone camera- by using either a double-sided ring sticker or with any other tape. Bring your phone's camera near blude side of the Foldscope's lens and it will automatically fit in place because of magnetic couplers. The magnified image of the sample is visible on the screen of the camera. Foldscope's lens has a magnification of 140x, and that magnification is multiplied by the zoom feature of the mobile phone. It is ideal for recording the movements of living specimens by using the video feature of the mobile phone. For a clear photo and video record, a sample can be illuminated by holding the yellow side of the Foldscope towards a light source (any natural or artificial source such as a clear sky, tube light or the LED magnifier light provided). In the third method, a sample can be projected on a white screen or surface in a dark room. Projection requires a strong light source. A phone's flashlight can also be used. For this, attach a magnetic coupler over the phone's flashlight, and then bring phone's flashlight up to the aperture on the yellow side of Foldscope. Turn on the flashlight and aim it at a flat white surface. An image of the specimen inserted in Foldscope™ will be visible on the screen.

Use of Social Media Networking with Foldscope™

An online community, MicrocosmosFoldscope, is a platform for sharing information gathered through Foldscope™ (https://microcosmos.foldscope.com). This platform has served as a scientific social networking site and location for sharing of ideas and explorations from remote areas of India and the entire world. Instructors and students can post their observations on this community by registering themselves using their email ID and a unique code provided with each Foldscope™.

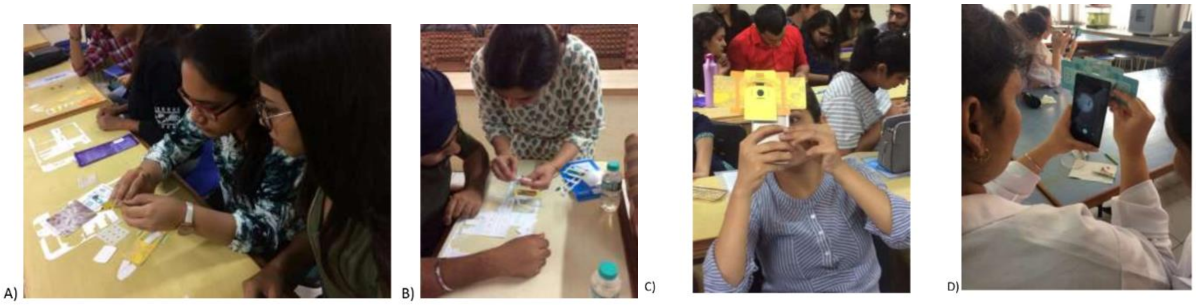
Methodology/the Process

The present article is an outcome of the observations revealing Foldscope™ usage. To use it as a teaching-learning tool, hands-on training sessions were conducted for undergraduate students during the 2018-2019 session. For this, a series of workshops and vacation camps (during summer and winter breaks) were organized by the Team Foldscope.IRB approval and student consent were obtained before conducting the workshop series. The instructors of all the workshops/ field visits conducted were the same so as to maintain uniformity. . In these workshops each participant was provided with a Foldscope™ sheet. After training to assemble and use these, students were encouraged to collect samples and explore on their own (Fig. 2).

The observations done by the team using Foldscope were posted on MicrocosmosFoldscope community with tags, # sd@foldscopechandigarh, and #Immuno@sdhawanchandigarh under # Indiafoldscopephase1.Students were able to perform on-site foldscopy with variety of samples collected during field visits and observe stained/permanent slides. A few of the explorations by the students during the field visits/workshops on Foldscope™ and captured with their smart phones as in Figure 3.

Figure 2

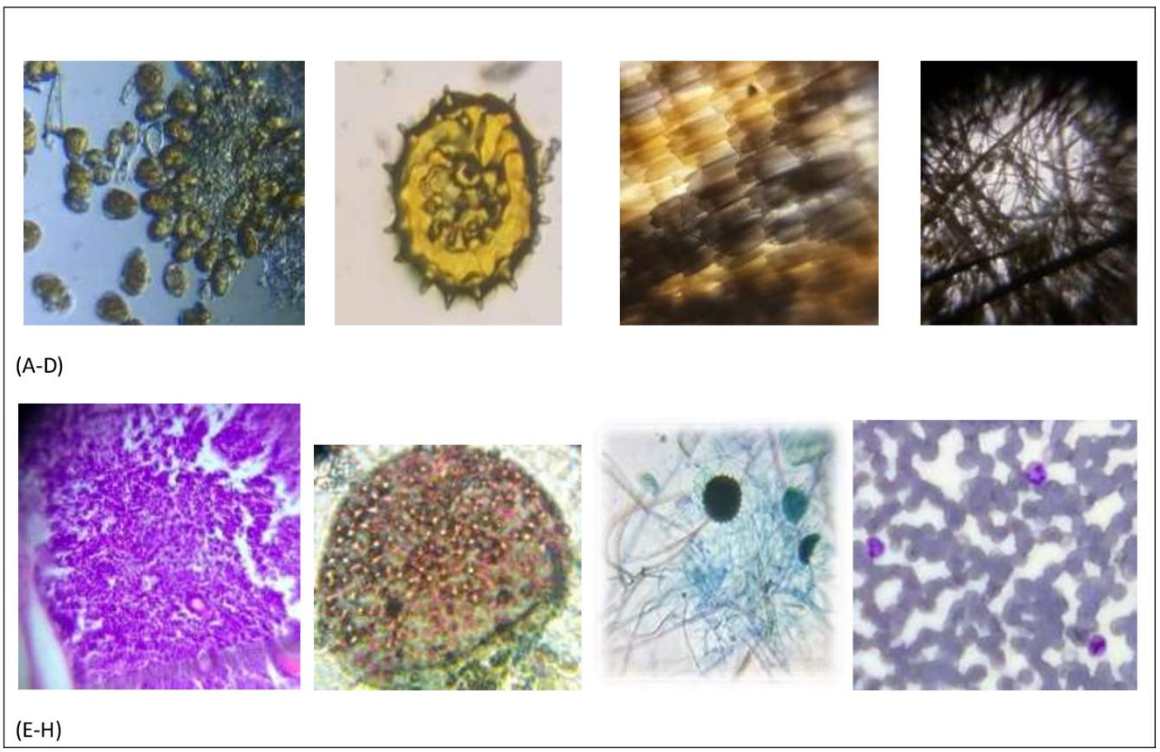
Foldscope workshop in progress at GGDSD College, Chandigarh, India



A) Undergraduate students attending workshop and assembling Foldscope™ from Foldscope kit components. B) An instructor helping to fold focus ramp for assembling Foldscope™. C) Another undergraduate student observing a *Volvox* colony while facing yellow side of Foldscope towards natural light. D) An undergraduate student excited to capture an image of focused slide on her smart phone.

Figure 3

Different explorations by undergraduate students using Foldscope™ and captured on smart phone



(A-D) On site observation of samples students collected during field visits. A) infected leaf of corn showing Rust of corn; B) Pollen grain of *Hibiscus*; C) Butterfly wing showing scales of butterfly. D) Entangled silk fibers of moth cocoon.(E-H) Observation of stained/ Permanent slides. E) Thymus-transverse section F) A *Volvox* colony G) *Rhizopus* Spores H) Human Blood smear.

General Observations and the Outcome of the Foldscope sensitization

Multifarious applications of Foldscope™

Foldscope™ was observed to be a multipurpose teaching and learning tool that may be useful for any educational institution. It can ignite young minds to come up with creative ideas.

An open school of learning

Age is no bar in usage of Foldscope™. It can be used by children, researchers, teachers or anybody who has the quest to learn. The students trained at the workshop were allowed to take the Foldscope home to explore on their own. It was commendable that they shared the idea and had involved their parents and grandparents in this activity.

The preliminary observations on use of Foldscope™ as an active learning tool in science classrooms of both undergraduate and post graduate students revealed that it is a practical tool that students can use individually in bigger classes where access to microscopes is limited and generally the student: microscope ratio is ≥ 50:1It can be used in cell biology, microbiology, parasitological, immunology, and histochemical studies of various plant and animal tissues. Foldscope™ use is feasible in a course with medical focus or in a forensic science course, where students could look at prepared slides independently, can perform preliminary screening of hair, blood samples and can use it for human blood histopathological examinations like cell counting and morphology analysis. (Waliullah, 2018).

Multi-faceted all-purpose tool

Reports shared on a social networking community from different groups using Foldscope™ working in India revealed its potential for various applications, suggesting that it might be useful in all these fields (https://microcosmos.foldscope.com):

Biodiversity and environment - It can be used for exploring floral and faunal biodiversity of different habitats.

-Monitoring soil and water quality-Foldscope™ can be used for detecting microbial contamination in potable water and microbial load of soil samples. It can significantly contribute to pollution abatement and can find its place in soil and water testing kits.

-Sanitation and Hygiene- This tool can be used to identify eggs or larvae of disease spreading mosquitoes in stagnant water and destroy them at source. It can also be used for maintenance of oral hygiene by suggested use in diagnosing infections in dental plaque.

-In checking adulteration of food items-Foldscope™ can be used to check adulterants in various food items. It is reported to check adulterants and contaminants in various feed and food ingredients in field conditions using Foldscope™ (https://krishikosh.egranth.ac.in/handle/1/5810139727).

-In minimizing post-harvest losses-The fungal and microbial growth can lead to post-harvest losses. The quality check of perishable foods and microbial spoilage can be easily detected using this waterproof, light weight tool.

-As a medical diagnostic tool-It can be used to detect hemoparasites like *Plasmodium*, *Trypanosomes*, *Schistosoma* (Ephraim et al., 2015) and other dangerous blood-borne infectious diseases and disorders of blood; for analysis of crystals in urine. It can be incinerated along with infectious biological samples for safe disposal. In the less-developed countries where price soaring health check-ups fail to diagnose the disease in time for treatment, Foldscope™ can serve as a low cost, high performance tool for rapid on-site analysis. Without any expensive lab equipment, its usage takes as little as 5 minutes. Being affordable, user-friendly, rapid, robust tool it held great potential to deliver point-of-care diagnostics even in the absence of any power source and internet facility (Ephraim et al., 2015; Hu et al., 2014).

As an In-field identification/learning tool

Field study is a vital component in addition to class-room sessions in effective Biology learning. Foldscope can shift the paradigm of research from laboratories to fields, experimental plots and even homes. It can be used by researchers in field as a tool for Plant Systematic, Palynological studies. For Plant pathology, it can be used to study symptoms of various diseases and microbial pathogens. It can be of great help to farmers in early identification of disease causing agents and communicate with regional agriculture officers in order to follow suitable control measures. The Foldscope Team explained the use and application of Foldscope for microscopic examination of leaves and plant parts to farmers and gardeners of Punjab and Sikkim to identify pests on plants (Fig. 2).

Role in online and distance education

The COVID-19 pandemic has led to digital transformation of education and online teaching. This immense shift from physical to digital education may persist to meet changing needs. Anticipating the future course of science education, a pedagogical change is expected in the teaching-learning environment in the post-COVID era. Physical distancing and social isolation measures, such as temporary closure of educational institutions and workplaces, have created an altogether different challenge. This cheap tool can facilitate practical learning of biology because of its portability. The omnipresence of mobile phones and the growing access to internet across the country can make mobile phone foldscopy a promising technology. It is leading to easy information sharing, making it a perfect tool for innovative Teaching Learning Practice both in offline and online mode.

General Observations and the Outcome of the Foldscope sensitization

Besides publishing diverse and dynamic posts on MicrocosmosFoldscope community, our team at GGDSD College, Chandigarh was able to discern three salient aspects of Foldscope™.

- Foldscope™ can be used as a learning tool both by students and teachers in conducting hands-on sessions within and beyond boundaries of classroom.
- Foldscope™ can be used as a basic research tool, thus laying a foundation for critical thinking. The students undertook short-term projects using Foldscope during their summer and autumn breaks, exploring and learning on their own by designing independent projects.
- Foldscope™ can be used as an in-field identification tool. Outreach programs conducted for people of diverse age groups and spectra of the society such as farmers and gardeners have demonstrated its potential as in-field identification tool for pests and pathogens.

Advantages and Disadvantages of Foldscope™

Structurally, its unique features allow an edge over the compound microscopes in terms of its portability, low cost, easy usage, easy availability, lack of energy and power requirements, and zero maintenance cost. Its portability allows on-site analysis anywhere. Foldscope™ is simple to assemble and can be operated by anyone with minimal training. It can be used for direct viewing with the unaided eye or coupled to mobile phone for viewing and for digital record keeping for future use.

Despite its several advantages, Foldscope™ has certain limitations

Although a Foldscope™ is ideal for viewing sub cellular structures, its resolution is still relatively low as compared to the high power of compound microscopes. It has a very small focus range so image analysis is difficult. It can be coupled only to smart phones. Foldscope cannot be used under dark conditions. A light source is required. The LED magnifiers provided in the kit can be attached to Foldscope™ to mitigate this problem.

It requires regular cleaning and maintenance and must be stored in dry conditions.

Safety issues for novice workers handling unknown microbial biological samples is another major concern. It must be used under the supervision of a competent person who understands the risks associated of working with unknown microorganisms.

For on-site biological fluid sampling, staining, and sample preparation can be major limiting factors, as can taxonomical identification and characterization of flora and fauna.

Conclusion

There is dire need to switch from the traditional chalk and talk approach of knowledge sharing to a learner-centric, agile, and self-learning approach in a developing country like India. Looking out for possible ways and means of imparting continuous learning are the objectives of the teachers and institutions in particular. For teaching and learning biology, the microscope is one of the most basic and powerful tools. But it is still inaccessible in under-resourced regions. The Foldscope™, a microscope that each student can own to learn biology easily is seen as a fitting substitute. Technology based tools that are easy to use and handle individually to avoid the community sharing to preclude contagious spread are being explored to meet the changed educational scenario in the Post COVID era. Though virtual labs can be the answer in the emerging scenario, wet lab simulation is a problem. Our explorations demonstrated Foldscope™ as an economical, ready to use, student-centric learning tool with potential to overcome the obstacles in disseminating science/biology education anywhere, anytime.

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Declaration of Interest

The authors declare no conflict of interest.

Editor’s note:

The authors supplied verification of permission to use student images.

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Wildlife and Waders: Experiences from a Biology Capstone Course

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Abstract

In fall of 2019, a new capstone course, wildlife biology, was offered as part of the biology curriculum at the University of Saint Joseph. The course fully embraced problem-based learning (PBL), project-based learning, and service-learning strategies. It provided a service to the campus community through the task of creating a management plan for two wetlands located on the campus given the problem of invasive plants. Student engagement in the topic and project was enhanced through the development of student teams and the opportunity to work with stakeholders. In responding to stakeholder project requests, students showed increased motivation, ownership in the project, and skill development. Through implementing this course, we unexpectedly observed increased development of students' leadership, maturity, and scientific curiosity.

Keywords: problem-based learning, service-learning, field biology, undergraduate biology

Introduction

Problem based learning (PBL) dates to the early 1960s as a novel educational method of teaching at McMaster University's medical school (Graaff and Kolmos 2007). This method engages students to seek answers in an active independent manner as opposed to being passively fed the information by an instructor (Graaff and Kolmos 2007). It has since seen successful use across the world in K-12 and secondary education and has been implemented in nearly all disciplines (Graaff and Kolmos 2007). While touted as the first pedagogy that promotes student-centered problem-solving learning styles, there are others such as case-study based learning (Hmelo-Silver 2004), service-learning (Furco 2011) and project-based learning (Graaff and Kolmos 2007). These varying pedagogy styles can overlap in practice or be carried out within a narrower scope. Case study and project learning as the terms imply, focus on material presented by the instructor to the students to work with or build from. Service learning has morphed over the decades and numerous definitions can be employed in its execution (Furco 2011), with the common element that a service must be provided to a body outside of the classroom (e.g. campus community, local town community, etc.). Thus, one can see that it is possible to combine some of these styles of learning for utilization in a course. One example would be combining service learning through the scope of a particular project and/or problem (PBL + Service learning; Tawfik, Trueman, and Lorz 2014) that is presented to students to solve. Elements of these three strategies were used in combination for the design of our Wildlife Ecology course and will be described here in this paper.

At the University of Saint Joseph (USJ) in West Hartford, CT, excellence in teaching is a priority for which innovation and active learning are encouraged. Several courses in the biology curriculum have included PBL, or at least parts of PBL, including: Advanced Cellular Biology, Introduction to Cellular Biology, Microbiology, and Principles of Environmental Science. Project based learning strategies has historically been embraced by the biology department as the Driving framework of its capstone courses by utilizing research projects in all capstone courses. Additionally, as a Mercy institution, the University's mission and core values ("USJ History, Mission & Goals" 2021) are reflected in various aspects of course work as well by developing a student's sense of responsibility to the needs of society through identifying where knowledge gaps exist and attempting to fill them through research. Student-centered problem-solving pairs well with community engagement and civic service, which is required of all USJ clubs, the honors program, sports teams, and some core curriculum courses. Therefore, it should be a natural fit for integration into more courses at USJ via research projects.

While the University of Saint Joseph's undergraduate Biology program is intended to provide students with a general exposure to topics from all the main branches of biology (molecular, cellular, organismal, and environmental), as is the case with many smaller liberal arts universities, most courses presently offered to students are in the health and biomedical based fields. Much of this stems from the fact that cellular and molecular focused courses are often "required" or at least "strongly recommended" courses for professional programs such as physician assistant studies, pharmaceutical sciences, and medical school. This creates an unbalanced curriculum with a deficiency in organismal, environmental, or ecological topics.

Currently, biology majors are only required to take two courses that focus on organismal or environmental biology. During their freshmen year, students take BIOL 117: Introduction to Evolution and Kingdoms, then during their sophomore year, students take BIOL 237: Principles of Environmental Science. At this time, there are no regularly available upper-level undergraduate organismal biology or ecological courses offered at the University. Therefore, a gap is apparent in providing students exposure to this valuable part of a general biology degree. This new capstone course is able to help in filling this gap.

As part of the biology degree requirements, all biology majors at USJ must complete the Biology capstone course. Students are not allowed to enroll in the capstone course until after they have completed all their mandatory required Biology classes (BIOL 114: Introduction to Cellular Biology, BIOL 117: Introduction to Evolution and Kingdoms, BIOL 232: Scientific Writing, BIOL 237: Principles of Environmental Science, and BIOL 250: Introduction to Biological Research). Capstone course topics change yearly. Only one capstone course is offered at a time each fall semester so that students do not have an option of choosing a specific topic. Following completion of the capstone course it is expected that students show mastery in quantitative reasoning, critique of logical arguments, and the ability to solve biological problems. In addition to learning new knowledge in the course, they are expected to pull upon information and skills learned in prior courses and utilize them in the capstone course.

At the 2019 Northeast Natural History Conference Dr. Chace presented information about a Conservation Biology course that he conducted at Salve Regina University in Newport, RI on Conservation Biology. The approach for Dr. Chace's course involved students working on a campus community-based project (Chace et al., 2018). Dr. Chace's presentation served as an inspiration for two University of Saint Joseph Biology faculty, Dr. Kirsten Martin and Dr. Michelle Kraczkowski, to develop a new capstone course for the biology program. In the fall of 2019, a new capstone course, wildlife biology, was offered to senior Biology majors at USJ. This paper presents a case study which will describe the course's development, execution, successes, and challenges encountered. The intent of sharing these lessons learned is to encourage others to be develop similar courses using such an advanced and combinatorial teaching strategy of PBL, project based, and service-learning.

Development

To maintain the ability to incorporate many different topics, the new course was broadly named "Wildlife Biology". To cover such a range of material, utilization of two instructors with complimentary expertise was ideal. One instructor's expertise included entomology, environmental science, and wildlife management, while the other instructor had expertise in fish biology and molecular ecology. However, both had general depth of knowledge and experience in the various field skills that were used throughout the course. Additionally, guests were brought in on four occasions to provide presentations or interest-based workshops on parasitology, aerial drone footage, and state wildlife management practices. Because this course would be utilizing the campus landscape and taking a project-based approach to solve a problem for the campus community's benefit, various stakeholders were necessary. The utilization of many experts and stakeholders was a unique and critical piece of the course development that moved the experience for students from a classroom setting to a "real world" setting.

Incorporating stakeholders provided students an incentive in the project as they could put a face to the name of who the resulting information from their project would be communicated to. The composition of the stakeholder group was diverse and included administration, facilities staff, colleagues from other disciplines, and other biology faculty. Two of the most important stakeholders were the University of Saint Joseph President Dr. Rhona Free, and the University of Saint Joseph Director of Facilities Andrew Levesque. Additionally, the Provost, the Dean of the School of Arts, Science, Business, and Education and the Biology Department Chair were all consulted and invited to be stakeholders. The "buy-in" of these stakeholders before the class even started was important. As these were upper-level administrators and colleagues, their approval and involvement had to be acquired and reserved prior to the start of the fall semester. This was accomplished at the end of the prior spring semester through a presentation, discussions, and meetings. Through these conversations, funding of new equipment for the course from Sodexo (the facilities contracted corporation) was secured and commitment by the stakeholder group for scheduling of meetings for the coming fall semester was obtained. The role of the stakeholder group was to not only support the initial development of the course, but to be an integral component of the course's project development throughout the semester by giving students feedback and guidance.

Students ultimately were working on developing a product that could be utilized by the administration to make decisions about the future of the campus landscape, specifically regarding the problem of invasive species in the wetlands. This made the role of the stakeholders into "clients" that the students were communicating with and working for. Therefore, the stakeholders had a "say" in the focus and outcome of the project that the students had to respond to. The incorporation of stakeholders presented challenges, but they were outweighed by the benefits of their involvement. The setting was the first challenge, in that students hardly interact with administration; therefore, the students were intimidated. However, this was also a motivating factor that forced them to prepare very well for each stakeholder meeting (four in total). Another challenge was to move students out of a classroom frame of mind where they are given instructions and then they execute, because in these meetings they had to lead and drive the conversation in order to maintain their agenda and get answers to their questions. This too can be viewed as a strength as it placed the students in a real-world scenario, providing them skills that would not normally be learned. Lastly, from the instructor perspective, relinquishing some control was a challenge, as ultimately the students needed to respond to the requests put forth by the stakeholders. The instructor's role was to provide them the means (teaching them field and computer skills) and direction (guidance on implementation and data collection design) for how to get there. However, this provided students with the opportunity to strengthen their leadership, critical thinking, and communication skills. Providing an opportunity to grow all of these skills simultaneously was a unique experience and an outcome of this course that would not have likely occurred in their prior educational experiences.

The wildlife biology capstone course focused on encouraging students to examine interactions between organisms and their environment and consider how these interactions might be applicable to wildlife management practices. The course had a very flexible design, with content instruction and lab experiences being blended (often to accommodate weather). The class was designed around a semester-long class project (problem= investigation and management suggestions for two wetlands on campus). The class-project provided students with the real-life task of working with stakeholders to address a problem, investigating through fieldwork and research, and ultimately providing updates and a product to the stakeholders that specifically addressed their issues of concern. While this was an upper-level class, and students had not had any introductory material in the content area, the focus of the wildlife biology capstone course was not to teach large quantities of upper-level content, but rather as a background for setting the stage in which they would work to acquire new skills. The instructors specifically designed the course in a way to encourage students to become active participants, and ultimately leaders in the project. The ultimate goals of this capstone course were the development of a management plan for the chosen area and to leave a legacy of learning beyond the end of the class. It was evident that there was some success in achieving both these goals, as students did develop a comprehensive management plan for use by USJ and several students went on to further pursue field research projects.

While a syllabus, a "projected course schedule", and a textbook were initially provided to students, the class had a flexible structure based on student interests and learning needs. Class topics also shifted based on the elements brought up in the stakeholder-student discussion meetings that were held periodically throughout the semester.

Course Design

The design and implementation of this class was very far removed from the classic "lecture and lab" that students were used to. The course had to be designed to be as flexible as possible because many of the meetings would entail students doing field work, and thus, weather dictated moving some tasks to later dates. With the input by the stakeholders, it would also be necessary to remain flexible to adding elements as much as possible. One unexpected influence on the need for a flexible schedule was the length of time that the students took to perform field work. What had not really been accounted for was that nearly all these students, even though they were seniors had only had one course that entailed substantial field work. Much of the field work required students to implement new skills, their learning curve often resulted in extra time in a subsequent class meeting as necessary to complete the tasks.

Depending on what prior courses students had taken they may or may not have been exposed to PBL, project-based, or service-learning previously. The course was designed to provide the students with learning new skills and information in the context of a singular class project that everyone contributed to. Many challenges were faced in this course, including student buy-in, independent learning, teamwork, equal contributions of effort, problem solving, self-confidence, autonomy over design, working outdoors, and insect phobias. To explain a few of these in more detail, it is important to acknowledge that the typical PBL is more case study oriented. These students were presented with a study subject, in this case, wetlands, and were asked to study them in detail in order to generate solutions to a problem of landscape management of invasives. This open-ended instruction was unsettling for many of the students because they wanted to know what it was that they were looking for or what would be the "right" data that they should include in their final report. Answers to these questions did not exist yet, as that was the whole point of their project; there was a gap in knowledge about these wetlands on campus and they needed to fill it. This led to an issue in their self-confidence, as they did not feel they were "qualified" to be doing this. There was an instance during a stakeholder meeting that a student asked of the stakeholders "Do you really have confidence that students can get you good data?". Their answer was emphatically yes. The stakeholders also trusted the instructors to provide quality assurance, but they felt that the senior biology students would be more than capable of not only completing but doing a professional job on the project. This was a major defining moment for some of the students. Hearing that the stakeholders truly believed in them really seemed to increase their confidence and resulted in fewer repeated questions to the instructors. That stakeholder meeting was also a turning point in how the students viewed the overall project. Following that meeting, students seemed to take more ownership of the project, and students also started to take their leadership roles within the groups more seriously. It was interesting and a surprising development to see them "quality-check" each other's work.

Another challenge of the course design was that as a capstone course, this was an upper-level class, which did present some challenges to students. The novelty of the material in the book and information presented in class did overwhelm some of them. This was evident in their quiz scores that assessed material that they were expected to read from the book and was similarly reflected in their report writing. While this challenge was not necessarily overcome during the course, it did distinguish the A level from B level students in the course as these assessments took up approximately 25% of their grade.

The last major challenge to explain in this course was teamwork. This coupled with the need for independent work left many to flounder in their confidence and leadership skills, resulting in a desire to "sit on the side-lines". For example, to survey the wetland's regarding width and length, manoeuvring through dense brush was necessary in some locations. The class of 13 had been divided into 3 groups of 3 and one with 4, therefore, they had to work with their group to collect the data on a certain section of their assigned wetland. The instructors could not hover over every group all the time due to the multiple locations; so student groups had to work independently and were checked in on periodically. Ever group was also given a walkie talkie in case of emergency and to communicate between wetlands. However, some groups did not communicate well with each other within groups, and were therefore slow to make decisions, missed some data points or got duplicates, and/or executed the field work incorrectly. The instructors therefore had to work very hard to manage these issues and facilitate resolutions through mediation in the groups.

One interesting characteristic about this class that has not been discussed yet, is the fact that the class was entirely made up of female students. It is unlikely that the make-up of the class had much impact on their involvement in the project, as this senior cohort of students was one of the last all-female cohorts. USJ made the decision to become co-ed at the undergraduate level two years prior. The students did seem to want to make a statement about their all-female class, however, because when they were asked to come up with a name for their group, they chose to call themselves "Women of Wildlife".

Success Stories

The course was successful in many ways, including production of a final management plan for the two wetland areas and development of an involved stakeholder-student partnership, but perhaps most importantly the class was successful in its ultimate goal, fostering of both academic and personal growth in the students. Through the experience of having to navigate group dynamics, learn new methodologies, problem-solve, and present to peers there were many examples of increased confidence and leadership skills in many of the students. Students were constantly out of their comfort zone, as they were dealing with unfamiliar environments, topics, and probably the most intimidating of all, the prospect of having direct interactions with the stakeholder group. Initially the thought of having to present and discuss project progress with the President of the University, the Provost, the Dean of the School and others, seemed impossible to the students, and they often looked for guidance and support from the instructors. By the final stakeholder meeting, however, students were able to interact directly with the stakeholder group in a mature and professional manner.

Student ownership of the project and professional pride in the integrity of their work also increased over the course of the semester. As students became more invested in the project, they began to become more actively involved in the path that the project took. At the start of the semester, students would often revert to the more traditional "student in a lecture classroom role" and would only respond to questions directly asked of them, but once they began to be immersed in the fieldwork, communication (both between students and with the instructors) really flourished. Students seemed to learn as much about themselves and their interactions within and between groups as they did about the project. Awareness of the value of the wetland areas also increased. This was evidenced through students becoming quite protective of the habitats and concerned about the potential impacts of littering and campus construction on the health of the wetlands.

Reflection

There was a lot of learning that occurred during this class, both for the students and certainly for the instructors. Following the end of any course, once the dust has had time to settle a little, reflection can occur in earnest to develop ways to improve the course for the future. If given the opportunity to run this course again, one change to implement would be creating a "contract of participation". Continuing along the lines of "buy-in", that is one thing that could have been strengthened from the start, as opposed to having to reel them in when effort was not being put in uniformly. If the students were charged with creating the contract as a group, agreeing upon it, and then everyone signing it, it would be more meaningful and potentially lead to them holding each other accountable, vs. relying on instructors solely for that. A contract also increases transparency of the course expectations and confirms that everyone is starting off in the same place. The growth of leadership and responsibility was again a wonderfully unexpected result of the course, so ways to further enhance that would be beneficial.

There is also an opportunity to reflect on what unexpected impacts the course may have had on the students, the campus community, and the instructors. One of the most unexpected impacts of the course was the continued interest by several of the students to extend their experiences through independent field research. Three of the students decided to work with the course instructors to further develop and conduct field research projects in subsequent semesters. One of the students was so inspired by the class, that she approached her town's conservation commission to get approval to complete an extensive wildlife assessment of a town-owned wetland. This student has recently enrolled in the master's in biology program at USJ and is interested in continuing her wetland assessment work as part of her thesis project. Interestingly, for two of these students, their work and projects were in fields of biology that had not been their primary interest, as one is now starting pharmacy school and the other is applying to Physician's Assistant programs. This speaks volumes about the applicability of the course and further emphasizes the importance of providing students exposure to a broad array of topics in order to increase environmental literacy. If we, biology programs, strive to make well rounded students and well-informed citizens, then comprehensive capstone courses in a biology curriculum are key steppingstones for undergraduate careers. Hopefully, other instructors are inspired by the information provided in this case study to try a similar teamwork style of implementing a PBL, project based, service-learning course curriculum that revolves around a singular community serving focus for their own courses.

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Bioscene: *Journal of College Biology Teaching*
Submission Guidelines

I. Submissions to *Bioscene*

Bioscene: Journal of College Biology Teaching is a refereed publication of the Association of College and University Biology Educators (ACUBE). Bioscene is published online only in May and in print in December. Submissions should reflect the interests of the membership of ACUBE. Appropriate submissions include:

- Articles: Course and curriculum development, innovative and workable teaching strategies that include **some type of assessment** of the impact of those strategies on student learning.
- Innovations: Laboratory and field studies that work, innovative and money-saving techniques for the lab or classroom. These do not ordinarily include assessment of the techniques' effectiveness on student learning.
- Perspectives: Reflections on general topics that include philosophical discussion of biology teaching and other topical aspects of pedagogy as it relates to biology.
- Reviews: Web site, software, and book reviews
- Information: Technological advice, professional school advice, and funding sources
- Letters to the Editor: Letters should deal with pedagogical issues facing college and university biology educators

II. Preparation of Articles, Innovations and Perspectives

Submissions can vary in length, but articles should be between 1500 and 5000 words in length. This includes references and tables, but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. Topics designated as acceptable as articles are described above. The formats for all submissions are as follows:

A. Abstract: The first page of the manuscript should contain the title of the manuscript, the names of the authors and institutional addresses, a brief abstract (200 words or less) or important points in the manuscript, and keywords in that order.
B. Manuscript Text: The introduction to the manuscript begins on the second page. It should supply sufficient background for readers to appreciate the work without referring to previously published references dealing with the subject. Citations should be reports of credible scientific or pedagogical research.

The body follows the introduction. Articles describing some type of research should be broken into sections with appropriate subheadings including Materials and Methods, Results, and Discussion. Some flexibility is permitted here depending upon the type of article being submitted. Articles describing a laboratory or class exercise that works should be broken into sections following the introduction as procedure, assessment, and discussion.

Acknowledgment of any financial support or personal contributions should be made at the end of the body in an Acknowledgement section, with financial acknowledgements preceding personal acknowledgements. If the study required institutional approval such as an Institutional Review Board (IRB), the approval or review number should be included in this section. For example, this study was approved under the IRB number 999999. The editor will delete disclaimers and endorsements (government, corporate, etc.)

A variety of writing styles can be used depending upon the type of article. Active voice is encouraged whenever possible. Past tense is recommended for descriptions of events that occurred in the past such as methods, observations, and data collection. Present tense can be used for your conclusions and accepted facts. Because *Bioscene* has readers from a variety of biological specialties, authors should avoid extremely technical language and define all specialized terms. Other than heading titles, the first word in a sentence or a proper noun, authors should not use capitalization, underlining, italics, or boldface within the text. Authors should not add extra spaces or indentations, should not use any hidden from view editing tools, should not use footnotes, and should not use a reference manager to develop the reference list. All references should be entered individually and follow the current APA latest edition Publication Manual. The text font for the entire document should be Calibri 10 point. All weights and measures must be given in the SI (metric) system.

C. In text citations:

Single Author:

"… when fruit flies were reared on media of sugar, tomatoes, and grapes" (Jaenike, 1986).

Two Authors:

"…assay was performed as described previously (Roffner & Danzig, 2004).

Multiple Authors:

"…similar results have been reported previously (Baehr et al., 1999).

D. References

References cited within the text should appear alphabetically by the author's last name at the end of the manuscript text under the heading references. All references must be cited in the text and come from published materials in the literature or the Internet. Authors should use the current APA style when formatting the reference list.

It is important to note the formatting. Articles with incorrectly formatted reference lists may be returned to the authors for corrections. Note that only the initials and the first letter of the full name of an author are capitalized.

The following information and examples for referencing and constructing tables, and figures were taken from the ***Publication Manual of the American Psychological Association: The Official Guide to APA Style***, 7th ed.

(1) Articles

Articles without a DOI

(a) Single author
Anderson, M. (2018). Getting consistent with consequences. Educational Leadership, 76(1), 26-33.

(b) Two authors
McCauley, S.M., & Christiansen, M.H. (2019). Language learning as language use: A cross-linguistic model of child language development. Physiological Review, 126(1), 1-51.

(c) Multi-authored three to seven authors:
Green, H., Goldberg, B., Schwartz, M., & Brown, D. D. (1968). The synthesis of collagen during the development of Xenopus laevis. *Developmental Biology*, *18*(4), 391–400.

(d) Mutli-authored more than seven authors
List the first six authors than an ellipsis followed by the last author.

Articles with a DOI

(e) McCauley, S.M., & Christiansen, M.H. (2019). Language learning as language use: A cross-linguistic model of child language development. Physiological Review, 126(1), 1-51. https://doi.org/10.1037/rev0000126

(2) Chapter in an edited book

Book without a DOI, from most academic research data bases or print version

(e) Weinstock, R., Leong, G.B., & Silva, J.A. (2003) Defining forensic psychiatry: Roles and responsibilities. In R. Rosner (Ed.), *Principles and practice of forensic psychiatry* (2nd ed., pp 7-13). CRC Press.

Book with a DOI

(f) Balsam, K.F., Martell, C.R., Jones, K.P. & Safren, S.A. (2019). Affirmative cognitive behavior therapy with sexual and gender minority people. In G. Y. Iwamasa & P. A. Hays (Eds.),*Culturally responsive cognitive behavior therapy: Practice and supervision* (2nd ed., pp 287-314). American Psychological Association. https://doi.org/10.1037/0000119-012

(4) Web sites

Webpage on a website with a group author

(g) Centers for Disease Control and Prevention. (2018, January 23). *People at high risk of developing flu-related complications*. https://www.cdc.gov/flu/about/disease/high_risk.htm

Webpage on website with an individual author

(h) Martin Lillie, C.M. (2016, December29). *Be kind to yourself: How self-compassion can improve your resiliency*. Mayo Clinic. https://www.mayoclinic.org/health-lifestyle/adult-health/in-depth/self-compassion-can-improve-your-resiliency/art-20267193

E. Tables

Tables should be submitted as individual electronic files in Word (2013+) or RTF format. Placement of tables should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible.

All tables must be on a separate page and in a Word editable format. Figures should not be constructed using the cut-and-paste technique nor be a snapshot of a table. Tables that are not editable may result in the return of the manuscript to the author. The figure legend should be as a Word document on a separate page. The legend should be brief but descriptive

Tables will appear in the final text as follows:

Table 1.
A comparison of student pre-test and post-test scores in a non-majors' biology class.

F. Figures

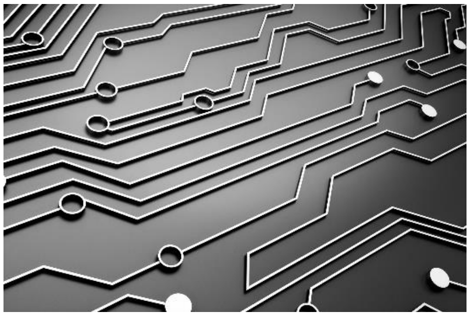
Figures should be submitted as **high resolution** (≥ 300dpi) individual electronic files, either TIFF or JPEG. Placement of figures should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. Figures only include graphs and/or images. Figures consisting entirely of text will not be accepted and must be submitted as tables instead.

All figures must be on a separate page and in a Word editable format. Figures should not be constructed using the cut-and-paste technique nor be a snapshot of a figure. Figures that are not editable may result in the return of the manuscript to the author. The figure legend should be as a Word document on a separate page. The legend should be brief but descriptive.

Figures will appear in the final text as follows:

Figure 1.

Polytene chromosomes of Drosophila melanogaster.



III. Letters to the Editor

Letters should be brief (400 words or less) and direct. Letters may be edited for length, clarity, and style. Authors must include institution address, contact phone number, and a signature.

IV. Other Submissions

Reviews and informational submissions may be edited for clarity, length, general interest, and timeliness. Guidelines for citations and references are the same for articles described above.

V. Manuscript Submissions

All manuscripts are to be sent to the editor electronically and must comply with the same guidelines for text, figure and table preparation as described above. *Authors must clearly designate which type of article they are submitting (see Section I) or their manuscript will not be considered for publication.* Emails should include information such as the title of the article, the number of words in the manuscript, the corresponding author's name, and all co-authors. Each author's name should be accompanied by complete postal and email addresses, as well as telephone and FAX numbers. Email will be the primary method of communication with the editors of *Bioscene*.

Communicating authors will receive confirmation of the submission. Manuscripts should be submitted either as a Microsoft Word or RTF (Rich Text File) to facilitate distribution of the manuscript to reviewers and for revisions. A single-email is required to submit electronically, as the review process is not necessarily blind unless requested by an author. If the article has a number of high resolution graphics, separate emails to the editor may be required. The editors recommend that authors complete and remit the Bioscene Author Checklist with their submission in order to expedite the review process.

VI. Editorial Review and Acceptance

For manuscripts to be sent out for review, at least one author must be a member of ACUBE. Otherwise, by submitting the manuscript without membership, the corresponding author agrees to page charges. Charges will be the membership fee at the time of submission per page. Once the authors' membership or page charge status has been cleared, the manuscripts will be sent to two anonymous reviewers as coordinated through the Editorial Board. Reviewer names and affiliation will be withheld from the authors. The associate editors will examine the article for compliance with the guidelines stated above. If the manuscript is not in compliance or the authors have not agreed to the page cost provisions stated above, manuscripts will be returned to authors until compliance is met or the page cost conditions have been met. Reviewers will examine the submission for:

- **Suitability:** The manuscript relates to teaching biology at the college and university level.
- **Coherence:** The manuscript is well-written with a minimum of typographical errors, spelling and grammatical errors, with the information presented in an organized and thoughtful manner.

- **Novelty:** The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

Once the article has been reviewed, the corresponding author will receive a notification of whether the article has been accepted for publication in *Bioscene*. All notices will be accompanied by suggestions and comments from the reviewers. The author must address all of the reviewers' comments and suggestions using the original document and **track changes** for any consideration of a resubmission and acceptance. Revisions and resubmission should be made within six months. Manuscripts resubmitted beyond the six-month window will be treated as a new submission. Should manuscripts requiring revision be resubmitted without corrections, the associate editors will return the article until the requested revisions have been made. Upon acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website. Time from acceptance to publication may take between twelve and eighteen months.

VII. Revision Checklist

Manuscripts will be returned to authors for failure to follow through on the following:

A. Send a copy of the revised article **using track changes** for text changes back to the associate editor, along with an email stating how reviewers' concerns were addressed.
B. Make sure that references are formatted appropriately in APA style format as noted above.
C. Make sure that recommended changes have been made or a clear explanation as to why they were not.
D. Figures and legends formatted appropriately and submitted on separate pages. The desired placement in the manuscript should be clearly indicated.

VIII. Editorial Policy and Copyright

It is the policy of *Bioscene* that authors retain copyright of their published material.