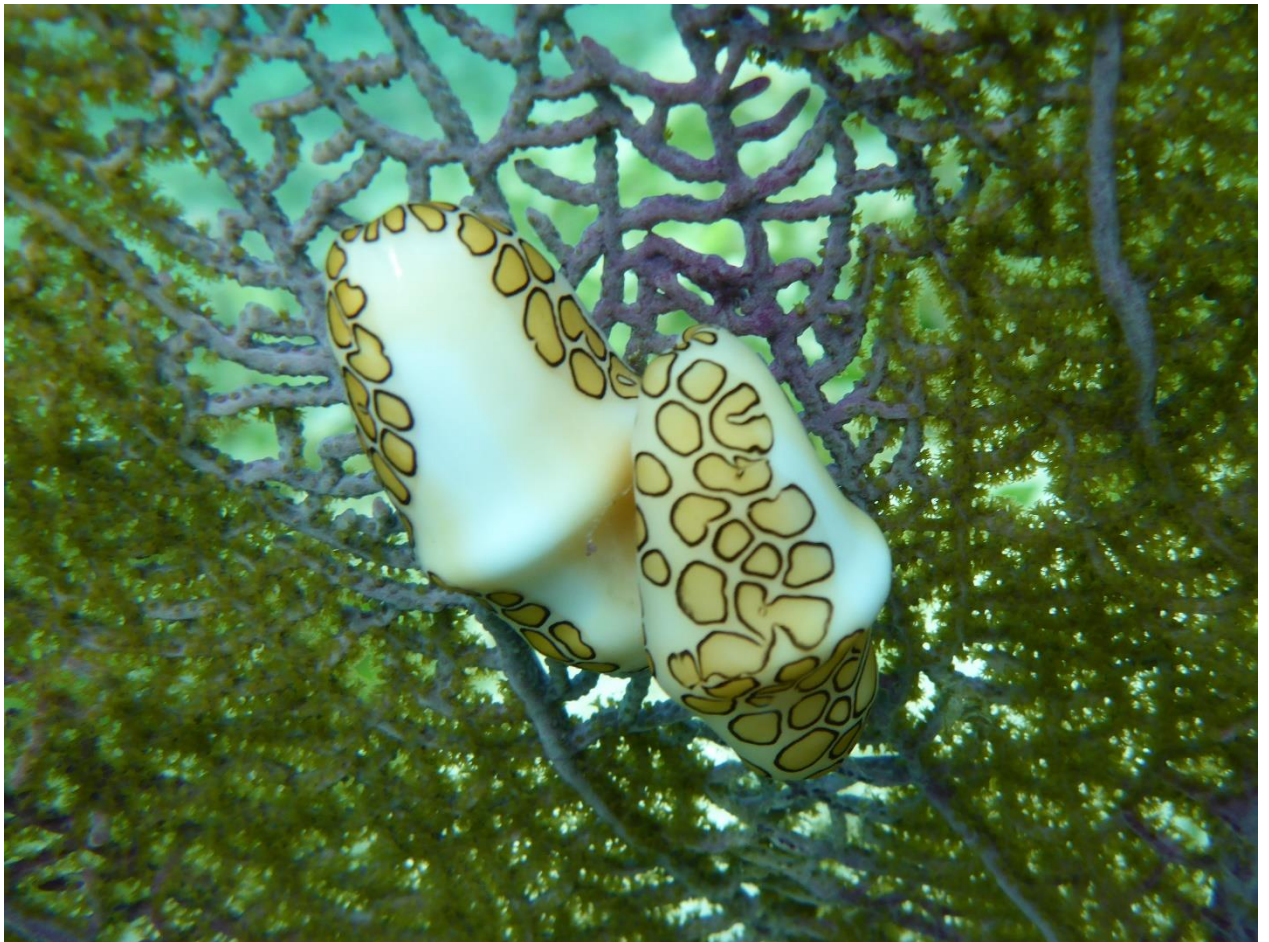


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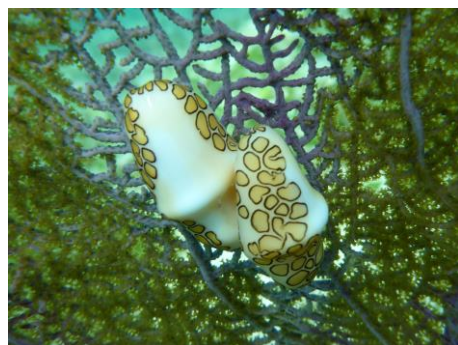
**Association of College and
University Biology Educators**

Editor-in-Chief:

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Cover image:

Flamingo tongue snails (*Cyphoma
gibbosum*) feeding on a common sea fan
(*Gorgonia ventalina*)

Location:

Shallow reef within the Sapodilla
Cayes Marine Reserve, Gulf of
Honduras,
Belize

Photographer:

Paul Pickhardt, Associate Professor
of Biology, Lakeland University

CONTENTS

EDITORIAL & GOVERNANCE INFORMATION.....2

ARTICLES3

Spanish-language Version of the Science Identity Survey (SISE):
Translation, Cultural Adaptation, and Evaluation.....3

*Liz Hernandez-Matias, Pablo A. Llerandi-Román, Lizmar Pérez-Donato,
Natalia Calzada-Jorge, Stephanie Mendoza, Faviola Laureano-Torres,
A. Valance Washington, Michelle Borrero*

INNOVATIONS

Plant Tracer: A Program to Track and Quantify Plant Movement from
Cellphone Captured Time-Lapse Movies14

*Angelica M. Guercio, B.A., Yixiang Mao, M.S., Victor N. D. Carvalho,
M.S., Jiazhen Zhang, B.S., Changyuan Li, M.S., Zheng Ren, M.S., Winnie
Zhao, Yao Wang, Ph.D., and Eric D. Brenner, Ph.D.*

The Color of Survival: An Inquiry-based Inter-disciplinary Study of Bacterial
Pigments22

José de Ondarza, Ph.D.

Using Student-generated Press Releases in a Vertebrate Physiology Course to
Enhance Scientific Communication Skills31

Shawn K. Stover

Linking Phrases for Concept Mapping in Introductory College Biology34

Robert Javonillo, and Catherine Martin-Dunlop

PERSPECTIVES

Why Teach Biology If It Is Rejected? How to Teach Evolution So That It
Can Be Accepted39

Clinton Laidlaw and Jamie Jensen

SUBMISSION GUIDELINES..... 48

64th ANNUAL MEETING

The 64th Annual ACUBE meeting will be held at Rockhurst
University on Friday October 23rd – Saturday Oct 24th in Kansas
City, MO.

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Articles

Spanish-language Version of the Science Identity Survey (SISE): Translation, Cultural Adaptation, and Evaluation

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Abstract

Multiple worldwide efforts, including research experiences and internships for students, have been developed to increase diversity in STEM. In order to understand the outcomes of these research experiences, instruments have become available, but surprisingly, Spanish instruments for these purposes are scarce. The evaluation of diverse scientific experiences and their influence on science identity is imperative. For this reason, we aimed to translate, and evaluate a Science Identity Survey for Puerto Rican high school students. A committee of experts evaluated the original survey of Science Identity and it was translated to Spanish using back-translation. Think-aloud results revealed that students' perception of their: (1) science competence is based on their grades, understanding, knowledge, and learning; (2) performance is based on design and completion of a scientific task; (3) recognition is based on the value that others give to science. The survey was analyzed to determine its dimensionality and reliability. A Cronbach's alpha of .857 was obtained, which suggests that the items have a good internal consistency. Exploratory factor analysis was performed and three factors; competence, performance and recognition were retained. This version of the survey was deemed to be an appropriate instrument to address student science identity.

Keywords science identity, high school students, Spanish translation, quick assessment, scale

Introduction

A recurring global issue in Science, Technology, Engineering and Math (STEM) education is the poor academic performance and retention of students. (Sithole et al., 2017; Therriault et al., 2017). Multiple worldwide efforts, including research experiences and internships for students, have been provided to increase diversity in STEM. (Eeds et al., 2017; Laursen et al., 2010, 2015; Lopatto, 2010). In order to identify program outcomes and define gains, multiple surveys have been developed (Corwin et al., 2015; Hanauer and Dolan, 2017; Lopatto, 2004, 2010; Weston and Laursen, 2015) and a growing body of research has been reported (Bauer and Bennett, 2003; Hathaway, 2002; Kardash, 2000; Kremer and Bringle,

1990; Lopatto, 2004, 2007; Lopatto and Tobias, 2010; Russel, 2007). Some examples of developed surveys and instruments are the Classroom Undergraduate Research Experience (CURE) survey, Survey of Undergraduate Research Experiences (SURE), Laboratory Course Assessment Survey (LCAS), Project Ownership Survey (POS) and Undergraduate Research Student Self-Assessment (URSSA).

While each of the aforementioned surveys measure research experience outcomes, each of them evaluates the experience within a particular theoretical framework. For example, the project ownership survey (POS) measures project ownership, and positive emotions towards the experience of the laboratory course (Hanauer and Dolan, 2017). The

CURE survey focuses on measuring the outcomes of research experiences by using a pre-course survey, a post-course survey, and an instructor report of course elements (Lopatto, 2010). The pre-course survey is focused on student level of expertise, science attitude, and learning style. The post-course survey estimates cognitive gains and benefits as well as attitude towards science. The SURE survey focuses on gains in laboratory technical skills, independence, intrinsic motivation, active participation and personal skills (Lopatto, 2004). LCAS measures students' perceptions of biology lab courses; in particular it is focused on collaboration, discovery, relevance, and iteration (Corwin et al., 2015). URSSA measures personal gains related to research work, skills, attitudes and behaviors, as well as thinking and working like a scientist (Weston and Laursen, 2015). The data gathered with these instruments and other research strategies has found that undergraduate research allows students to acquire beneficial learning and personal gains such as concept understanding, thinking like scientists, elucidation of what they want to study, and whether to further pursue graduate education, specifically in STEM.

Although these instruments comprised multiple important factors that influence research experiences and persistence of different populations including Latino/Hispanic populations, the impact of scientific experiences on the science identity of Latino/Hispanic high school students remains incompletely defined. Due to the increasing population of high school students whose first language is Spanish, it is critical to understand the science identity of them taking into consideration culturally-patterned differences, native language, and familiar concepts to obtain a better understanding of their science identity (Ramirez et al., 2017). Since diversity and inclusion of everyone into science, including the Latino/Hispanic population, is important for the nation's economic and social development, the study of science identity and key components for retention is imperative (Malcom and Feder, 2016). Unfortunately, in a review of the literature, no single validated Spanish-language assessment instrument for science identity was found.

Identity as described by Gee (1991) is "the kind of person one is seeking to be and enact in the here and now". When it comes to science identity, researchers agree that there is a component of self or intrinsic factors and a component of fitting into the norms and practice of the scientific community that leads to the recognition of the person in the specific community. A growing amount of research has argued that the components that build up students' science identity offers "the most complete understanding of students' trajectories and persistence in science related careers" (Fraser and Ward, 2009; Krogh and Andersen, 2013).

Although science identity has taken many different meanings, we will focus on the definition given by Carlone and Johnson (2007) because of their methodological and practical implications. This selection does not deny other useful approaches that could be taken using other definitions; it gives us a framework for data analysis and interpretation.

Carlone and Johnson's approach to define and contextualize a science identity model is formed by the following question: "How would we describe a person who has a strong science identity?" They define the science identity concept as the kind of person that "makes visible to (performs for) others one's competence in relevant practices, and, in response, others recognize one's performance as credible" (2007). In other words, their science identity model captures the key elements that build and describe a person that belongs to the scientific community. Interestingly, this model is based on the interrelated dimensions of competence, performance and recognition that an individual can envision at different degrees and configurations (Carlone and Johnson, 2007). Competence is defined as "knowledge and understanding of science content"; performance is defined as "social performances of relevant research practices such as: ways of taking and using tools"; and recognition by "recognizing oneself and others as a "science person" (Carlone and Johnson, 2007).

Multiple researchers have developed surveys addressing science identity (Cole, 2012; Estrada et al., 2011; Hanauer, et al. 2016; Schon, 2015; Stets et al., 2016; Vincent and Schunn, 2018). These instruments attempt to define science identity using the following constructs: self-identification, performance, recognition, students' interests related to science, reflected appraisals, science self-efficacy, science behavior, interest, fascination, values, competency beliefs, project ownership, emotion, and networking. Among the surveys that study students' science identity and follow the structure and specific dimensions of Carlone and Johnson is Jennifer Schon's Science Identity Survey (SIS) (Schon, 2015). The SIS instrument measures intrinsic and extrinsic components of science identity using 15 items. Although the SIS instrument measures competence using knowledge and understanding of science topics, these items are not content-based and therefore can be used for the evaluation of interventions of a wide range of topics. Its length and approach make this instrument suitable for the evaluation of a variety of short interventions. Therefore, we have selected this survey to study high school students' science identity.

The SIS was translated, contextualized, and evaluated (Schon, 2015) with Spanish-speaking, Puerto Rican high-school students as research

subjects. Survey evaluation was conducted following amixed method approach, as the one performed by the original SIS developers (Schon, 2015).

SIS development and use

The SIS was created to evaluate the impact of students' experiences at informal education centers (Schon, 2015). Since informal education experiences, such as museums, afterschool programs, and activities in off-school venues differ in style, context, and content, the developers of the survey created a short non-content based survey to evaluate students' experiences based on a mixed method approach (Schon, 2015). First, interviews were held to gather insight on student's scientific experiences. Items were then constructed, followed by think-aloud and pilot testing (Schon, 2015).

The three different dimensions or constructs of science identity described by Carlone and Johnson: competence, performance, and recognition were included and studied in the SIS. The competence category consists of 5 items that are related to student perception of knowledge and learning. Performance consists of 5 items based on student perception of science skills as experimental design, making observations, and using the scientific method. Recognition includes 5 items that identify if the students feel like a scientist or if they perceive that friends or relatives see them as scientist. For each of these categories, a 5 to 1 Likert scale from "Strongly agree" to "Strongly disagree" was used.

The original instrument was used for 5th and 6th grade students at the University Of Idaho College Of Natural Resources' McCall Outdoor Science School (MOSS). For the confirmatory factor analysis, they report the following indices: comparative fit index (CFI) = .934, adjusted goodness of fit index (AGFI) = .869, root mean square error of approximation (RMSEA) = .07, standardized root mean squared residual SRMR= .065. This instrument was further used to evaluate students' science identity before and after an informal education experience at MOSS. Also, a follow up evaluation was performed after a month. Results showed that the experience at MOSS was a positive influence on the participants' science identity (Schon, 2015).

Methods

Participants

The Institutional Review Board at the University of Puerto Rico approved this study (IRB protocol 1718-036). Participants did not receive any incentive for their participation. Anonymity of all participants is guaranteed. We selected participants based on their grade level (10th, 11th and 12th grade), and

availability and willingness to complete the survey. An informative brochure of the study together with the consent/assent form was given to students. Two weeks after the initial approach, consent/assent forms were collected and during the same day, participants answered the survey or participated in interviews. Survey content evaluation was addressed using the think-aloud method (Trenor et al., 2011). One group of three and another of four students participated in this process to confirm that participants understood the intended meaning of the questions. A preliminary evaluation was performed with 32 participants (19 females and 12 males) from one school located in San Juan, Puerto Rico. For the construct evaluation, three different high schools from the San Juan region were approached. The participants' schools were selected according to their specialization (science, sports, or languages) in order to include students with a diverse range of interests. A total of 180 participants completed the survey.

Translation

The SIS was translated from English to Spanish as suggested by the World Health Organization guidelines (2007). A bilingual translator, who was familiar with science identity constructs, and whose mother tongue is Spanish performed the forward-translation step. Once the initial translation was completed, a bilingual panel composed of 4 experts in the field of science, education, translation, and/or instrument development discussed each item. The expert panel evaluated each item for discrepancies between the original version and the translated version, cultural discrepancies, concept translation, jargon, and clarity. Once the expert panel solved discrepancies and reached a consensus on all items, the revised Spanish version was given to an independent translator whose mother tongue is English and did not have any knowledge of the studied concepts of science identity. The independent translator translated the Spanish version of the survey back to English (backward translation). Subsequently, the expert panel compared the English version of the survey to the original version and discrepancies were discussed until conceptual and cultural equivalence of the survey was achieved. Each panel discussion took approximately 4 hours.

Survey content evaluation

The final version of the translation process was given to groups of 4 participants as suggested by Virzi (1992). Participants were asked to answer: (1) what was their first thought about the item, (2) what was their answer, (3) if something was not clear, and if so, what was not clear to them, and (4) if they had a suggestion to improve the item. Participants evaluated

each item and their suggestions were incorporated in the survey. The final version of this process was a consensus among all the participants. At the end of the process, the interviewer read out-loud the survey and final changes, or suggestions were incorporated. This process was repeated until it reached saturation of responses (Trenor et al., 2011).

Survey construct evaluation

Think-aloud suggestions were incorporated into the survey and administered to participants. During this process we realized that the numbered Likert scale was not clear to participants. For this reason, we incorporated another session of think-aloud with 4 additional participants, in which two versions of the survey were given, one with a scale labeled with numbers and another one labeled with descriptive word answers. Participants were asked to answer the survey in both formats and talk about their answer selection process allowing us to define and correct any misconception and select the best scale format for our survey.

The survey was administered to 180 participants. Survey descriptive statistics, reliability, and goodness of fit analysis were calculated using IBM SPSS Statistics software package, version 24. Cronbach's alpha was used to estimate the internal consistency of the survey (Cronbach, 1951). Measurement criterion was as followed: $\alpha \geq 0.90$ (high internal consistency or items may be redundant) $\alpha \geq .80$ (good internal consistency) $\alpha \geq .70$ (adequate internal consistency) (Nunnally, 1978). Skewness and kurtosis acceptable criterion for normality was set at $|2.0|$ as suggested by George D. and Mallery P. (2010). Kaiser-Meyer-Olkin, measure (KMO) of sampling adequacy threshold was set at 0.5 as used by Hanauer and Dolan (2014).

Students' perceptions of their competence, performance and recognition are variables that cannot be directly observed (latent variables). To study these unobservable variables, we analyze participants' responses to specific questions (measurable variables) to make inferences about the studied latent variables. Exploratory Factor Analysis (EFA) with principal axis

extraction method was selected instead of the Principal Components Analysis, because we wanted to determine interpretable constructs that explain correlations among measurable variables and not in find components that explain as much variance as possible (Preacher and McCallum, 2003; Knekta, Runyon and Eddy, 2019).

To identify the best structure to interpret our results we rotated the factor solutions. Among the rotation methods that are available we selected the oblimin method, which allowed correlation among factors (Preacher and McCallum, 2003). Parallel analysis was performed to determine the number of factors to retain; Principal Axis Factor was used as the method of extraction, 1000 data sets, 95 percentile, and Pearson correlation (O'Connor, 2000).

Characteristics		Number students
Age range	14-17	
Female		93 (1.6%)
Male		86 (48%)
Other		1 (0.5%)
Metropolitan area of San Juan*		155 (86%)
Other [#]		25 (14%)

Table 1. Student demographics. *including Bayamón, Carolina, Cataño, Guaynabo, and Trujillo Alto. # Corozal, Gurabo, Toa Baja, Aguas Buenas, Dorado, Juncos, Las Piedras, Vega Alta, San Lorenzo, Río Grande, Canóvanas.

Results

Participants

Participants' age ranged from 14 to 17 years old (Table 1). The proportion of females and males was fairly evenly distributed, but overall more females participated. Most of the participants live in the metropolitan area of San Juan, Puerto Rico. As it is shown in Tables 2 and 3, some participants failed to indicate their parent's highest degree obtained, field of study, and/or occupation because they had no knowledge about this information, declined to answer,

Education	High School	Two-year Associate	Bachelor's Degree	Post-graduate or Professional Degree*	N/A ⁺
Father highest degree obtained	9 (5%)	5 (3%)	57 (32%)	57 (32%)	52 (29%)
Mother highest degree obtained	24 (13%)	5 (3%)	38 (21%)	42 (23%)	71 (39%)

Table 2. Parents highest degree obtained. *including master's, doctorate, medical or law degree. +don't know/refused to answer.

	N/A ⁺	STEM	Other
Father field of study	68 (38%)	33 (18%)	79 (44%)
Mother field of study	37 (21%)	36 (20%)	107 (59%)
Father occupation	32 (18%)	27 (15%)	121 (67%)
Mother occupation	31 (17%)	23 (13%)	126 (70%)

Table 3. Parents field of study and occupation. ⁺don't know, refused to answer, unemployed.

or left unanswered because it didn't apply to their case. From the participants who answered, most of their

parents obtained a postgraduate or professional degree (includes Master's, Doctorate, Medical, or Law degrees). A few participants had parents who graduated from Associate degree programs. Most parents studied in a field and/or have an occupation that is not related to STEM.

Content evaluation

Two groups of four participants discussed each item of the Spanish-translated version of the survey, suggesting a total of 8 changes, all of which were incorporated (Table 4). Changes were mainly focused on verb usage and the inclusion of not just task, but projects in item number 12. Participants also requested to delete "mis" ("my") on item number 13, (Las personas me ven como un científico cuando comparto

Original questionnaire	Translated questionnaire	Incorporation of think-aloud suggestions
1. I am good at science	Soy bueno en ciencia.	Soy bueno en ciencia.
2. I know a lot about science	Se mucho de ciencia.	Se mucho de ciencia.
3. I am good at most science experiments	Soy bueno haciendo experimentos científicos.	Soy bueno llevando a cabo experimentos científicos.
4. I understand science topics	Entiendo fácilmente los temas de ciencia.	Domino los temas de ciencia.
5. I learn new science topics easily	Aprendo fácilmente nuevos temas de ciencia.	Aprendo fácilmente nuevos temas de ciencia.
6. I can use science equipment and/or technology to collect data	Puedo usar equipos científicos y/o tecnología para obtener datos.	Puedo usar equipos científicos y/o tecnología para obtener datos.
7. I know how to use the scientific method/process	Se cómo usar el método científico.	Se cómo usar el método científico.
8. I can talk with others about science related topics	Puedo hablar con otras personas sobre temas de ciencia.	Puedo hablar con otras personas sobre temas de ciencia.
9. I can create my own science experiments	Puedo crear mis propios experimentos científicos.	Puedo diseñar mis propios experimentos científicos.
10. I can use my observations to create a hypothesis	Puedo usar mis observaciones para hacer una hipótesis.	Puedo usar observaciones para hacer una hipótesis.
11. My friends see me as someone that is good at science	Mis amigos me ven como una persona que es buena en ciencia.	Mis amigos me ven como una persona que es buena en ciencia.
12. When giving a science report, I feel like a scientist	Cuando hago mis trabajos de ciencia, me siento como un científico.	Cuando hago trabajos y/o proyectos de ciencia, me siento como un científico.
13. Others see me as a scientist when I share my observations	Las personas me ven como un científico cuando comparto mis observaciones.	Las personas me ven como un científico cuando comparto observaciones.
14. When I share data I've collected, I feel like a scientist	Cuando comparto los datos que he obtenido me siento como un científico.	Cuando comparto los datos que he obtenido me siento como un científico.
15. I can help others with science related topics	Puedo ayudar a las personas cuando tienen dudas de ciencia.	Puedo ayudar a las personas cuando tienen dudas de ciencia.

Table 4. Translation of the items and the result of think-aloud process. Translation of the Science identity questionnaire published by Jennifer Schon was performed using back-translation followed by a committee expert evaluation. Think-aloud was performed twice using a group of 3 to 4 students.

“mis” observaciones) since they feel like scientists when they are sharing observations of other scientists as well as their own.

Participants also commented that the numbered scale is subjective, and the descriptive scale is clearer to them. From the think-aloud interviews we gathered the following participants’ quotes (see translated English version at the bottom of each quote):

“Me enfrento a la escala de palabras y mi humildad toca la puerta. En la escala de palabras valgo menos.”

“When I am confronted with the words scale my humility knocks on the door. With the words scale I feel of less value”

“Es más claro (en palabras), número es más subjetivo.”

“It is clearer (in words), numbers are more subjective”

“Palabras es más claro”.

“With words it is clearer.”

“Con números la interpretación es diferente; es subjetivo.”

“With numbers the interpretation is different; it is subjective”

Therefore, the following descriptive word scale was incorporated: “Muy de acuerdo”, “De acuerdo” Ni en desacuerdo ni de acuerdo”, “En desacuerdo”, and “Muy en desacuerdo”. The modified version was administered to 180 participants for construct evaluation.

Answers mean value for the items ranged from 2.8 to 4.3 (Table 5). All the items had a skewness and kurtosis below |1.0|. Intra-subscale correlations ranged from 0.325 to 0.724 and communalities range from 0.463 to 0.785. Results show a Chi-Square, value of 1125.633 significance 0.000, Cronbach’s alpha coefficient value of 0.867, and Kaiser-Meyer-Olkin, measure (KMO) of sampling adequacy of .855. Also, a Bartlett’s test of sphericity, tests of correlation matrix, showed a significance of 0.000. After the analysis and interpretation of the measurements above

Item	Mean	Std. Deviation	Skewness	Kurtosis	Corrected Item-Total correlation
1	3.8	0.84313	-0.528	0.664	0.602
2	3.4	0.7907	-0.015	0.271	0.591
3	3.9	0.82827	-0.402	-0.31	0.438
4	3.6	0.79451	-0.386	0.793	0.615
5	3.7	0.84643	-0.379	0.184	0.568
6	4.2	0.72541	-0.759	0.689	0.473
7	4.2	0.69171	-0.318	-0.501	0.325
8	3.9	0.89872	-0.571	-0.349	0.503
9	3.4	0.92727	-0.089	-0.326	0.406
10	4.3	0.60051	-0.208	-0.573	0.355
11	3.4	1.06871	-0.242	-0.448	0.724
12	3.4	1.14525	-0.265	-0.678	0.374
13	2.8	0.92244	-0.027	-0.033	0.59
14	3.2	1.13551	-0.146	-0.769	0.491
15	3.7	1.01882	-0.651	0.176	0.661

Table 5. Descriptive statistics for each of the items. n=180

Number of items	15
Number of responses	180
Average inter-item correlations	0.306
Standard deviation of Inter-item correlations	0.15
Cronbach’s alpha	0.867
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.855
Bartlett’s Test of Sphericity	1125.633
Bartlett’s Test of Sphericity Significance	0

Table 6. Scale and Reliability Statistics of the survey. 15 items, n=180

Component Matrix					
Item	1	2	3	4	Total variance explained
Soy bueno en ciencia.	.873				5.492 (33.71%)
Se mucho de ciencia.	.701				
Domino los temas de ciencia.	.699				
Aprendo facilmente nuevos temas de ciencia.	.654				
Puedo ayudar a las personas cuando tienen dudas de ciencia.	.590				
Mis amigos me ven como una persona que es buena en ciencia.	.565			-.402	
Cuando hago mis trabajos de ciencia, me siento como un científico.		.950			1.834 (10.174%)
Las personas me ven como un científico cuando comparto mis observaciones.		.801			
Cuando comparto los datos que he obtenido me siento como un científico.		.659			
Se cómo usar el método científico.			.704		1.478 (96.083%)
Soy bueno llevando a cabo experimentos científicos			.539		
Puedo usar equipos científicos y/o tecnología para obtener datos.			.494		
Puedo usar observaciones para hacer una hipótesis.			.419		
Puedo hablar con otras personas sobre temas de ciencia				-.643	1.02 (3.35%)
Puedo diseñar mis propios experimentos científicos.				-.431	

Table 7. Exploratory factor analysis. Using Oblimin rotation, four factors were found that explained 53.32% of the variance.

mentioned and descriptive statistics we confirmed that the sample was adequate and that its dimensionality could be explained using a factor analysis (Table 6).

The internal structure of the test items was identified using the exploratory factor analysis. Principal axis factoring using the oblimin with Kaiser normalization rotation was conducted. Results indicate a 4-factors solution (Table 7). The 4-factor solution explained 53.32% of the variance. Each item was explained by one factor, with the exception of item 11. Factor 1, which accounts for 33.71% of the explained variance, was constructed of competence and recognition items. Factor 2 (10.174% variance explained) was constructed of recognition items. Factor 3 (6.083% variance explained) was constructed of performance and one item of competences. Factor 4 (3.357% variance explained) was constructed of performance items.

In general, these factors were consistent with what was originally described for the SIS. In detail, the first factor, that comprised mainly competence items, included the following items that were previously categorized in the recognition dimension: “Mis amigos me ven como una persona que es buena en ciencia” (SIS original item: “My friends see me as someone who is good at science”), and “Puedo ayudar

a las personas cuando tienen dudas de ciencia” (SIS original item: “I can help others with science related topics”). In the think-aloud, participants commented that in order to help others and to be recognized as a person that is good at science, they needed to know the material and have good grades. Thus, they related these items to their ability to understand and know science topics, which directly associates to science competencies.

The third and fourth factors are mainly composed of performance items. One item previously included in the competence dimension: “Soy bueno llevando a cabo experimentos científicos” (SIS original item: “I am good in most science experiments”) was incorporated in the third factor. Participants’ interpretation of this item focused on experimental design, methods, and experimentation. Participants emphasized that the item is open enough that it can be interpreted as experimental design or experimentation. The fourth factor was composed of two performance items. According to the parallel analysis and because of the small number of items in factor 4, just factors 1, 2 and 3 were retained (Figure 1).

Based on the exploratory factor analysis, parallel analysis, and think-aloud comments we recommended a rearrangement of the items on each of the dimensions

and the deletion of original items 8, 9, and 11. Cronbach's alpha index was re-calculated for the final version of the survey and we obtained a result of .857. The final version of the survey is presented in Table 8 and it has incorporated the aforementioned modifications.

Discussion

Although science identity has been mainly studied in undergraduates or higher degrees, it is known that high school science identity is influenced by students' persistence, the role of the community, and level of science at school (Aschbacher et al., 2009). Unfortunately, the impact of scientific experiences on the science identity of Latino/Hispanic high school students remains relatively undefined (Gándara, 2006; Rochin and Mello, 2007; Tabak and Collins, 2011). To characterize the effectiveness of research experiences and identify which components actually are important for STEM retention of high school Latino/Hispanic population, an assessment in Spanish was necessary. This study presents evidence of the translation and evaluation of the Spanish version of the SIS (SISE, for SIS-Español), using Puerto Rican high school students as research subjects and takes into consideration culturally patterned differences.

After the think aloud process, participants agreed that the numbered Likert scale was subjective, and the descriptive word scale was more informative. For this reason, the original numbered scale on the SIS was replaced and the word descriptive scale was

incorporated. This result is consistent with previous research on scales that found that numbered scales are subjective to participant interpretations and are more problematic for respondents that do not tolerate ambiguity (Johnson et al., 2005). Interestingly, our results show that participants tend to assign higher scores when using the numbered scale

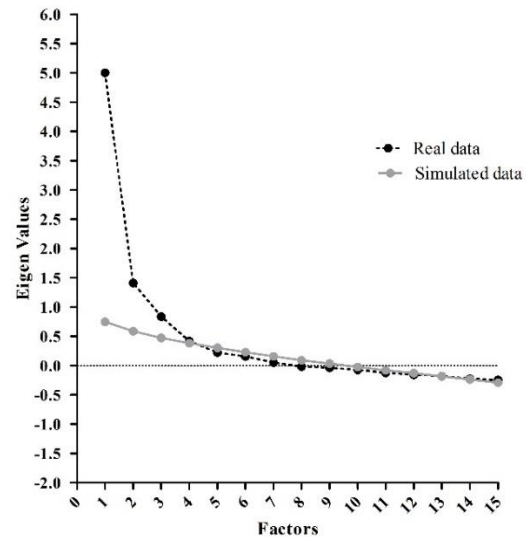


Fig 1. Parallel analysis. Method of extraction: Principal Axis Factor, 1000 data sets, 95 percentile, and Pearson correlation.

	Muy de acuerdo	De acuerdo	Niem desacuerdo nide acuerdo	Em desacuerdo	Mu yen desacuerdo
1. Soy bueno en ciencia.					
2. Se mucho de ciencia.					
3. Soy bueno hacienda experimentos científicos.					
4. Entiendo fácilmente lose mas de ciencia.					
5. Aprendo fácilmente nuevos temas de ciencia.					
6. Puedousar equipos científicos y/o tecnologiaia para obtenere datos.					
7. Se cómo usar elmétodo científico.					
8. Puedo usar observaciones paraq hacer una hipótesis.					
9. Cuando hago mis trabajos de ciencia, me siento como un científico.					
10. Las personas me ven como un científico cuando compartomi observaciones.					
11. Cuando comparto los datos que he ob tenido me siento como un científico.					
12. Puedo ayudara las peronsasw cuando tienen dudas de ciencia.					

Table 8. SISE Suggested changes

than when they are using the descriptive word scale. This effect may be influenced by the submissive response (*simpatía*) style documented among Latinos and Hispanics (Johnson et al., 2005). Our results suggest that the use of a descriptive word scale can help participants to think about the best word that describes their answer and not on giving the highest score possible to each item.

After content evaluation and scale changes, an exploratory factor analysis and Cronbach's alpha index were calculated to explore the structure and reliability of the survey. A 4-factor solution was suggested, but one of the factors was not reliable. As a result, this factor was deleted.

Limitations and Suggestions

One limitation of the SIS is that its evaluation was performed using just one informal center. Given that participants of the SIS evaluation were self-selected, they may have a predisposition to science careers and this selection process excluded those students that may not like science and are not interested on a STEM career. To overcome this limitation, we chose schools specialized in various areas to have a diverse group of students with different levels of interests in science. We are aware that this selection does not imply or ensure participants' interest for science, but it does gather different student profiles. A potential limitation of the survey for future SISE users is that it has only been validated with Puerto Rican high school' students, and there are cultural differences across Spanish-speaking communities. We encourage future users of the SISE to validate this survey with a similar population to the one that will be further tested, taking into account culturally patterned differences and scale interpretations.

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Declaration of Interest

The authors declare no conflict of interest.

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Innovations

Plant Tracer: A Program to Track and Quantify Plant Movement from Cellphone Captured Time-Lapse Movies

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Abstract Despite the fundamental importance of plants to our very survival, student interest in plant biology is in decline as technology draws us further away from nature. Here we introduce *Plant Tracer* (<http://www.planttracer.com>), a Matlab-based program, which can quantify time-lapse videos of plant movement. We demonstrate that Plant Tracer can be used to distinguish altered movement qualities in the inflorescence (flowering) stem in the *Arabidopsis pgm-1* (phosphoglucosyltransferase) mutant when compared to wildtype, providing a genetic platform for students to evaluate how plants sense and respond to gravity and circumnutation (the back-and-forth swaying of plant organs). We show that both gravitropism and circumnutation is diminished in the *pgm-1* mutant when compared to wildtype. In this way, *Plant Tracer* is a promising instructional tool for biology labs to quantify the genetics of plant movement using smartphones.

Keywords plant biology, plant movement, *Plant Tracer*, software, movement quantification, movement tracking, gravitropism, circumnutation, *Arabidopsis thaliana*

Introduction

Time-lapse photography has proven itself to be a promising instructional tool in biology lectures to stimulate interest in plants, enabling student visualization of the complexities of plant development and movement (Fitzgerald, 2012; Hangarter, 2000; Harrison-Pitaniello, 2013; Stark, 2008). Building upon this technology, a plant time-lapse photography educational lab was created where students use their personal digital devices to record and visualize movement in the flowering stems of the genetic model plant, *Arabidopsis thaliana* (Brenner, 2017). *Arabidopsis thaliana* exhibits rapid positional changes in the inflorescence in a little more than an hour (Brenner, 2017; Niinuma, 2005; Masson, 2002). This active learning lab not only increased student interest in plants but also inspired nearly half of the students to share their smart phone derived videos with friends and family (Brenner, 2017), effectively amplifying the educational impact of this approach.

While this method of having students create plant movement time-lapse movies was successful at increasing engagement, it yielded only qualitative, not quantitative data, hence, the development of software that not only tracks, but also analyzes plant movement is the logical next step for students to directly become active in the field of plant-movement research. Developing this method is especially useful in that currently available plant movement-tracking software is targeted exclusively to academic research laboratories, thus necessitating the use of expensive cameras, and requiring knowledge of computer coding languages (Stolarz, 2014; Wagner, 2017; Greenham, 2015). In addition, most existing plant movement tracking software is merely limited to examining only one type of movement, one organ, or one species of plant. Here we introduce a Matlab-based (MATLAB, 2015b) graphical user interface (GUI) software program, *Plant Tracer*, to not only bring the dynamism of the plant into the classroom, but also to provide investigators with tools to analyze this

movement and gather quantifiable data to better understand plant movements.

Among the fascinating and sophisticated movements that plants make are tropisms (movement towards or away from a stimulus), and nutations (back and forth movements that occur with no obvious stimulus). Time-lapse technology can capture these movements to stimulate student engagement by revealing this dynamism (Brenner, 2017; Fitzgerald, 2012; Harrison-Pitaniello, 2013; Hayden et al. 2011). Gravitropism, the re-orientation of plant organs in response to gravity has been well documented by Charles Darwin (Darwin, 1865). Darwin hypothesized in 1903 that the mechanism of gravitropism is activated by the settling of mobile starch-synthesizing organelles called statoliths in root tissue in response to gravity, and this hypothesis was further augmented by Zimmerman in 1924. Statoliths are easily stained and observed in the classroom, where they are found in the gravity sensing columella cells of the root cap (Kiss, 2000). It is still not known exactly how statoliths initiate the gravitropic cascade, but it is theorized that statoliths activate mechanosensitive pathways in the actin cytoskeleton that subsequently cause the asymmetric distribution of the major regulatory plant hormone auxin, causing a response in the stem to bend in reorientation against gravity (Chen, 1999; Blancaflor, 2003; Band, 2012; Wyatt, 2013). One strong piece of evidence that statoliths function as the, or one of the gravity vector sensor(s), comes from the *Arabidopsis* mutant, phosphoglucosyltransferase-1 (*pgm*) (Vitha, 2000; Weise, 1999). This mutant is blocked in a key step involved in starch formation, and thereby consequently deprived of statoliths (Weise, 1999). As a way of easily demonstrating the role of statoliths in shoot gravitropism, students can easily observe—during a single class laboratory—impaired shoot reorientation in *pgm-1* compared to wildtype (Kiss 2000).

Circumnutation is another type of plant movement. It is a complex and poorly understood process that is universal to all plants (Darwin, 1880; Stolarz, 2009). Circumnutation is the back-and-forth swaying found in plant organs (Darwin, 1880; Stolarz, 2009), but little is understood about why and how it occurs. Like all nutations, circumnutation is influenced, but also exists independently of external stimuli (Stolarz, 2009; Schuster, 2010). Circumnutation is influenced by the circadian clock, light, temperature, chemicals, organ morphology, and age (Stolarz, 2009; Schuster, 2010; Niinuma, 2005; Kitazawa, 2005). Circumnutation has been shown to be influenced by gravisensing cells, auxin, ion channels, and proton pumps but its mechanism and purpose is not well understood (Stolarz, 2009; Schuster, 2010; Niinuma, 2005; Kitazawa, 2005). To engage student interest in plants, circumnutation is a highly dynamic and intriguing process where one nutation (back and forth motion) can be observed

within one lab period using the model genetic plant *Arabidopsis thaliana* (Brenner, 2017).

With *Plant Tracer* students first create plant movement footage using the application Lapse It (<http://www.lapseit.com>) as described in Brenner, 2017 and then upload these time-lapse movies into *Plant Tracer* (which currently runs as an executable Matlab-originated (MATLAB, 2015b) program available for download), in order to quantify movement rate, and periodicity (distance moved) during gravitropism or circumnutation. *Plant Tracer* enables students to not only quantify changes in plant movement, but also compare movement values between different strains, mutants, and other plant variations for scientific discovery. Here we use *Plant Tracer* to demonstrate reduced movement qualities in the *Arabidopsis thaliana* mutant, *pgm-1*, when compared to wildtype.

Methods

Plant Tracer Software Development

Plant Tracer was developed in Matlab (MATLAB, 2015b) and functions as an executable program, allowing it to be downloaded without charge and to be run independently of the base program. *Plant Tracer* is installed on a personal computer running either Mac OS or Windows operating systems.

To track *Arabidopsis thaliana* apex movement, we modified the basic block matching algorithm to detect a moving inflorescence stem apex (Fig. 1) (Lu & Liou, 1997). This algorithm is used as a method of locating matching blocks in a sequence of digital video frames for the purposes of motion estimation. The underlying assumption behind this method is that the visual pattern of a block enclosing the apex stays approximately the same from frame to frame. In *Plant Tracer*, starting with a manually annotated block in an initial frame, its position in the current frame is determined by an exhaustive search, which calculates a matching cost function between the block in the previous frame and each candidate block in the current frame centered at each possible location in a search window. The candidate block with the least cost is then chosen for the current frame, and the process continues to the next frame.

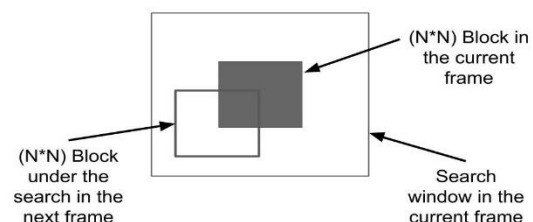


Figure. 1. Mechanism of Block-matching Algorithm.

$$\text{Cost Function} = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} |F_{ij} - C_{ij}| + W_2 \|\mathbf{x}_F - \mathbf{x}_C\|_2 + W_3 \|(\mathbf{x}_F - \mathbf{x}_C) - (\mathbf{x}_C - \mathbf{x}_P)\|_2,$$

Figure. 2. Cost Function Equation.

Block matching is based on minimizing a cost function (Fig. 2). In *Plant Tracer*, we have modified the cost function of the basic block-matching algorithm to incorporate constraints on possible apex movements.

The cost function equation is shown where N is block width (which is assumed to be the same as block height), F_{ij} and C_{ij} are the luminance intensity values of pixels in the current and previous blocks, respectively. \mathbf{x}_F , \mathbf{x}_C and \mathbf{x}_P are the block center coordinate vector in the current frame, the previous frame, and the previous frame before that, respectively. W_2 and W_3 are weighting parameters. The first term is the mean absolute difference (MAD) which calculates the intensity difference between two connected frames. The second term represents the distance the apex traveled between two frames. The third term is the difference magnitude of the apex movement in two successive inter-frame periods. Note that 2 indicates the L2 norm or length of a vector. By adding the second and third terms, we favor candidate blocks that undergo small and smooth motion from the previously determined blocks, among those that have similar MAD as the previous block. Through empirical trial and error with our testing videos, we set W_2 and W_3 to 0.375 and 0.175, respectively.

To alleviate the influence of any pattern(s) on the background on continuous tracking, we apply background subtraction prior to the block matching algorithm. Here we assume the background is stationary and obtain the background image for a frame by averaging the past 10 frames. Then, we subtract the background image from the current frame and threshold the difference image. For each pixel, if the absolute value of the difference is smaller than a threshold value, this pixel is set to 0 in the current frame. Otherwise, the original value is kept. We then apply the block matching algorithm on this background-removed frame. A threshold value of 20 is found to work well (the intensity range is from 0 to 255).

Plant Culture Methods

Standard *Arabidopsis* cultivation methods were performed as described according to Brenner (2017). Seeds from the *Arabidopsis thaliana* genotype Columbia (Col) as the control, and the mutant phosphoglucosyltransferase (*pgm-1*) (which can be ordered as a “teaching kit” through the Ohio Biological Resource Center (#CS19985)) were cultivated in 2 ½ inch (side) square plastic pots containing MetroMix 360 (Sun Grow) soil or on hydrated jiffy-7 soil pellets

(Carolina Biologicals). Water was applied to the tray under the flat holding the plants so that water seeped into the soil from below. In both cases plants were fertilized with water containing Miracle Grow Bloom Booster Flower Food fertilizer powder [NPK of 15-30-15, with the following microelements: B (0.02%), Cu (0.07%), Fe (0.15%), Mn (0.05%), Mo (0.0005%), and Zn (0.06%)] at day 10 after the seeds were sown. Plants were cultivated for approximately 4-6 weeks under fluorescent lights on growth carts. Light conditions consisted of 16 hours of light and 8 hours of dark.

Staging a Time Lapse Recording

Recordings were made using a standard portable electronic device such as a tablet or smartphone. The developmental stage used for this analysis is reached when the inflorescence stem is approximately 2-6 cm tall. At this stage the first flowers are just beginning to undergo anthesis (flowering opening). It is important to choose plants with only a small number of inflorescence shoots, or ideally a single shoot. If a plant with more than one shoot is tested for gravitropism, it is important to avoid situating the plant, so that one shoot might move across the path of another shoot, leaf, or other structure, which may cause the tracking algorithm to lose track of the subject.

During testing of either circumnutation or gravitropism digital recordings were made with *Arabidopsis* strain Columbia, as a control vs. the *pgm-1* mutant, as shown in Fig. 3. Key materials for the imaging set-up include a solid black background (shown here as a black office folder), a metric ruler (with white lettering and white increments set on a black background for best contrast). The ruler is used to calibrate the true distance within the movie. Labels are placed in close proximity to the plants so that the identity of the plant strain/genotype can be clearly seen in the recording.

An experiment designed to measure the movement parameters of gravitropism is initiated by tipping the *Arabidopsis* plant 90 degrees to position it on its side (Fig. 3); whereas, an experiment to measure circumnutation is set up by simply leaving the plants in their original upright orientation as shown in Fig. 3. For both gravitropism and circumnutation the ruler must be placed in the same focal plane as the apices so as to not distort the measured values.

Making Time-Lapse Videos with Lapse-It

Lapse It is a free, simple, and publicly-available time-lapse App compatible with Android and iOS

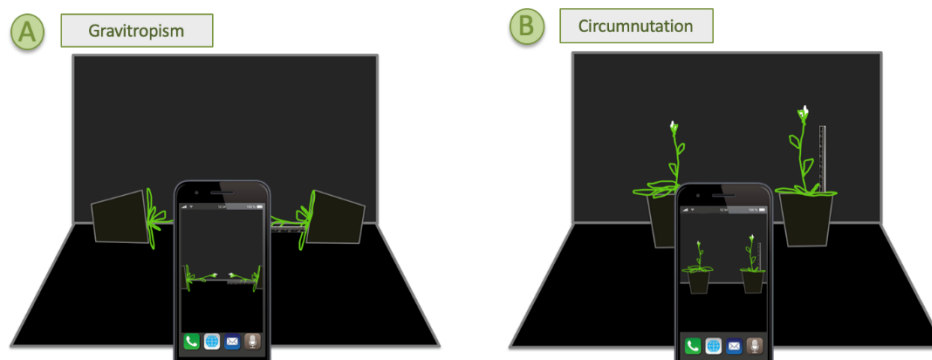


Figure 3. Experimental Staging of Time-lapse Recording

devices (<http://www.lapseit.com>). To create a time-lapse recording of Arabidopsis, in the Lapse-It settings page, the “Capture Interval” is set to capture an image once every two minutes and the render settings are set for 20 “Frames per Second”. Gravitropic analysis in Arabidopsis is typically complete after at least 1 hour and 30 minutes but can be run longer if desired. Circumnutation studies run for at least three hours minimum (the approximate time for one full nutation) but can be continued for 1-3 days (or until the apex has moved out of camera frame). Upon completion of the movie, the video should be “rendered” in Lapse-It and then saved to the device’s camera roll. The video should then be transferred to a computer for analysis using *Plant Tracer*.

Downloading and Installing *Plant Tracer*

An “executable” version of *Plant Tracer* can be downloaded at <http://www.planttracer.com>; *Plant Tracer* is compatible with both Mac and Windows operating systems. To download click on the Matlab icon on the website front page as shown in Fig. 4. In the downloads folder, double click on the ‘PlantTracer1.0-mac.zip’ or ‘PlantTracer1.0-windows.zip’ file to decompress the file. Then in the downloads folder, right click on MyAppInstaller and select open from the menu to begin installation. The program installer will pop-up, and you can navigate through the installer to complete installation. Once installed, navigate to the Applications folder the folder titled ‘PlantTracer’. In *PlantTracer* > application > one can find the PlantTracer program. Right click and select open to access the interface.

Using *Plant Tracer*

Before use it is helpful to view this tutorial video, showing how to utilize *Plant Tracer* for either circumnutation <https://www.youtube.com/watch?v=VN2cBPuqBzk>, or for gravitropism <https://www.youtube.com/watch?v=evsTLrZacwE> tracking.

The steps to use *Plant Tracer* for video analysis are also shown in Fig. 5. Analysis is initiated by



Figure. 4 The *Plant Tracer* Website. Arrow refers to Matlab icon. Click icon to initiate download of *Plant Tracer* program.

clicking on the folder (Icon 1) to upload a rendered Lapse-It video into *Plant Tracer*. Upon upload, the first frame of the video is shown in the viewer. There is a panel to the right of the viewer, where one enters information necessary for quantification. The first step is to trim the movie to the region of interest by using the slider bars at the bottom of the interface (Icon 2). If the software Lapse It was used to create the time-lapse movie, be certain to trim off the Lapse it logo that appears at the end of the movie. To do this, use the right slider to trim the logo (Icon 2).

Next, before ‘tracing’ plant movement, two parameters are inputted into *Plant Tracer*. First, the capture interval used to make the video is entered into the box beside “Capture interval” (Icon 3). The Capture interval is found in settings in Lapse It as pictures taken per minute (the default value of 0.5 [one picture is taken every two minutes] works well for recordings of Arabidopsis inflorescence stem movement). The second value to enter is the internal distance calibration. To do this, check the box beside “Set scale” (Icon 4). This will then prompt the user to click on two points in the video frame along the margin of the ruler to draw a straight line (“that spans a known distance”). After the line appears spanning the two clicked points, next right click or hit ‘enter’ on the keyboard to exit the line drawing mode. Next enter the value (in mm) of the length of the line drawn into the data entry box for “Set scale” (Icon 4). Next under the

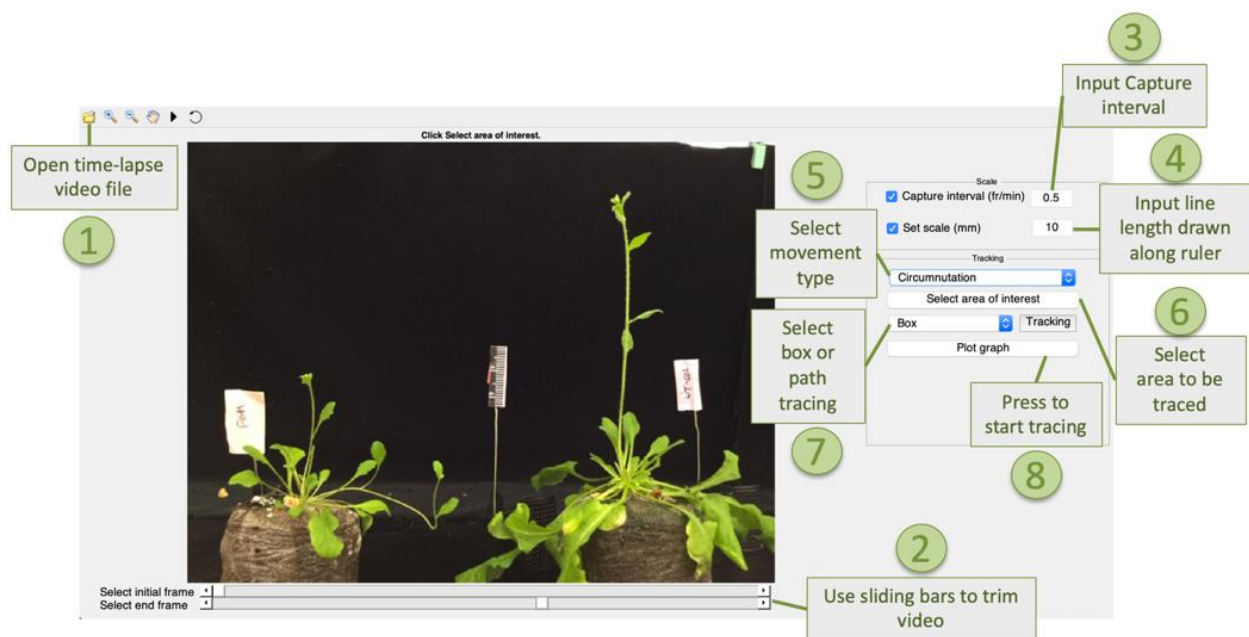


Figure. 5 The *Plant Tracer* Interface. Boxed text and lines in green point out action steps in the *Plant Tracer* interface to analyze a time-lapse movie of plant movement. Tasks should be completed in consecutive order from Icon 1 - Icon 8. See the video Circumnutation Tutorial at <https://www.youtube.com/watch?v=VN2cBPuqBzk> or Gravitropism Tutorial at <https://www.youtube.com/watch?v=evsTLrZacwE> for a descriptive walk through of the *Plant Tracer* program.

heading “Tracking” the user selects the plant movement behavior of interest, either circumnutation or gravitropism (Icon 5). Next, click on “Select Area of Interest” (Icon 6), which enables the user to draw a tracking rectangle on an organ, or segment of an organ to ‘trace’. Next, the user chooses either “Select box or path tracing” (Icon 7) to generate either a box or a tracing line that will follow the path of movement. Once the area of interest and movement type has been chosen, “Press to start tracing” (Icon 8) is clicked and

Plant Tracer will automatically run the block matching algorithm. While the computer is tracking the moving plant the program follows the path of the “gravitroping” or circumnutating selected object. By clicking on “Plot graph” the data output will create a graph revealing the x (horizontal) and y (vertical) components along a Cartesian (x,y) grid system of the positional changes of the object as shown in Fig. 6 A, B. For gravitropism, the vertical direction is chosen to measure the ascendance of the flowering stem apex.

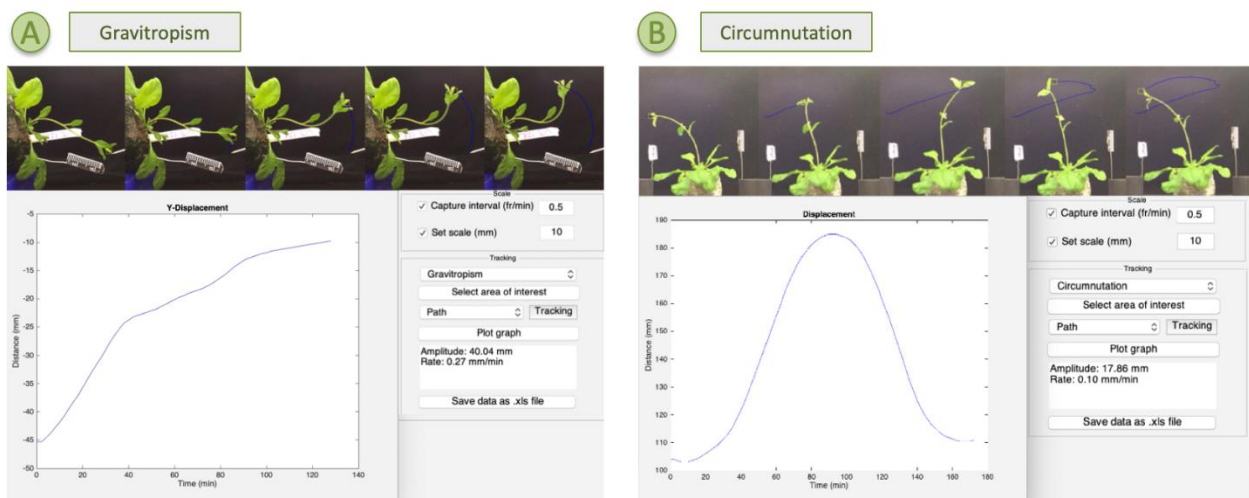


Figure. 6 Still shots reveal progression of plant movement during *Plant Tracer* analysis of gravitropism and circumnutation from *Arabidopsis thaliana* wildtype genotype, Columbia. Still shots demonstrate progression of movement coupled with an x,y output plot alongside the program interface. Movement calculations include amplitude and rate for A. vertical displacement during a gravitropism. B. horizontal displacement during circumnutation.

For circumnutation, the horizontal direction is chosen to measure the periodic back-and-forth swaying of the flowering stem apex. The output plot values are reported in the *Plant Tracer* including amplitude (mm) and movement rate (mm/min) flowering shoot apex (Fig. 6 A, B).

Results

Plant Tracer as a tool to measure plant movement

Plant Tracer is designed to measure plant movement from time-lapse recordings. In order to test the accuracy of *Plant tracer*, the actual distance an *Arabidopsis* apex moved was hand measured and compared to the software's calculated output. Whilst there are concerns about the 3-D movement of the plant being reduced to two dimensions, analyses of hand-measured vs Plant-Tracer computed amplitudes and rates of movement show no significant difference (Fig. 7).

We tested *Plant Tracer* to determine if it could detect impaired movement qualities in an *Arabidopsis thaliana* line that is deficient in gravitropism, the starch mutant line phosphoglucomutase, *pgm-1*, during both gravitropism and circumnutation in comparison to wildtype, Columbia. *pgm-1* has been previously reported to exhibit a slower gravitropic response in both movement rate and change in angle due to a perturbation of the starch-dependent gravisensing mechanism (17). In a pairwise comparison of 16 control Columbia plants compared to 16 *pgm-1* mutant plants, all mutant plants were shown to have significantly smaller amplitude of movement and a lower movement rate during gravitropic response (Fig. 8). Furthermore, *pgm-1* mutants showed a decrease in circumnutation rate and amplitude of horizontal movement (Fig. 8).

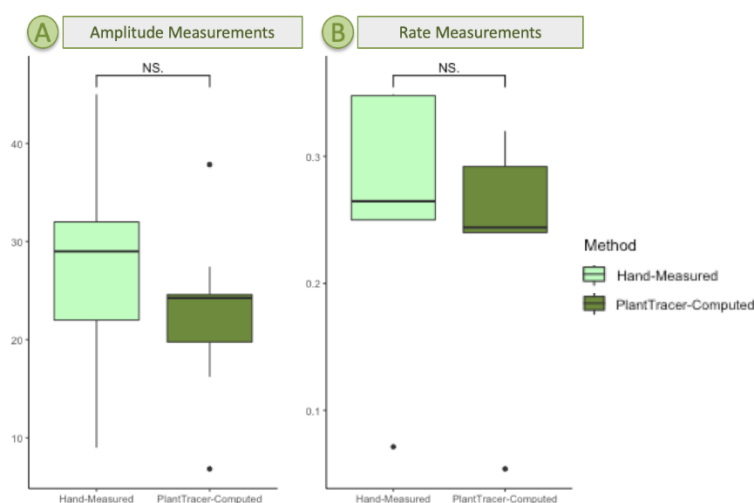


Fig. 7 Testing the accuracy of *Plant Tracer*. Comparative boxplots of hand-measured and *Plant Tracer*-computed amplitude measurements. Rate measurements are not significantly different.

Discussion

Time-lapse photography is an excellent way to discern and analyze plant movement and can encourage student interest in plant biology. It brings the plant world --that to many is often seen as static-- into the relatable dynamic present. Bringing the dynamism of plants to life makes plants more relatable and interesting to students. Along with this the *Plant Tracer* software also enables them to analyze the data from their videos to characterize this process.

While we have begun to use this software to look at circumnutation and gravitropism in a handful of *Arabidopsis* mutant lines, we envision the flexibility of the program to potentially measure other movement

properties in *Arabidopsis* and movement in other plant species in future iterations. We have chosen *Arabidopsis* because it has fast growth and movement, when compared to other easily grown species and also because it has tremendously rich genetic resources which would enable the further identification of genes that may be involved in movement processes (23). In addition, *Arabidopsis* is easily grown indoors and is highly suited for classroom studies (10, 23). Currently we are working to create a version of *Plant Tracer* that will operate independently on the smartphone, which we believe will dramatically increase usability among students (a beta test version of App can be download from www.plantracer.com). The development of *Plant Tracer* in Matlab is the first step

towards our ultimate goal of constructing a hand-held App. Through the use of *Plant Tracer* we aim to expose these dynamic processes to a wider audience,

as well as give students the opportunity to easily perform novel experiments and make original discoveries in the field of plant movement.

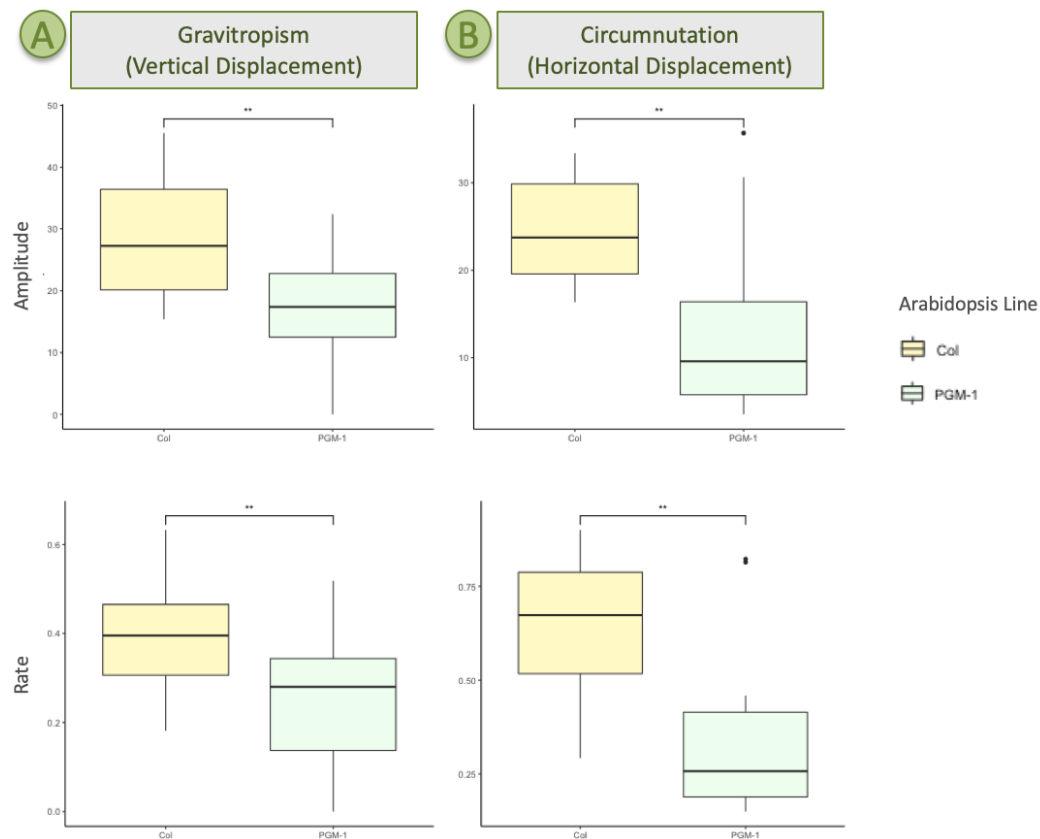


Fig. 8 Comparative analyses between *pgm-1* vs. Wildtype Columbia Arabidopsis lines. Boxplots show median value differences and 1st to 4th quartile differences between medians Columbia (yellow) vs. *pgm-1* starch mutant (green) lines after repeated tests (n=16, n=16). Asterisks indicate a significant difference in median values obtained via Student's t-test. One asterisk indicates $p < 0.05$, two $p < 0.005$, and three $p < 0.0005$ A. Amplitude and rate of vertical displacement (gravitropism) B. Amplitude and rate of horizontal displacement (circumnutation).

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The Color of Survival: An Inquiry-based Inter-disciplinary Study of Bacterial Pigments

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Abstract. Pigments are light-absorbing substances that are abundant in nature, serving roles in coloration, camouflage, mate/pollinator attraction and photosynthesis among higher life forms. Among microbial organisms, pigments can also be found in a wide range of phyla. While some of these pigments function in photosynthesis, namely among algae and some bacteria, the great majority of microbial pigments play entirely different roles. The exploratory study presented here will stimulate students to think about the cost and benefit of a heritable trait (pigment production) of microscopic organisms and its effects on survival in a competitive and hostile environment. Exploring and understanding the roles these pigments play allows for a number of cross-disciplinary learning opportunities that combine physics, chemistry, biology and even art, and can be set up as an inquiry-based learning module suitable for small-group and active learning experiences.

Keywords: Interdisciplinary; inquiry-based; bacterial pigments; microbiology; physics

Introduction

Pigment production in bacteria. If you have ever had the opportunity to grow bacteria in a classroom, you will likely have noticed that these microbes can be surprisingly colorful. I am fascinated by the colors produced by bacteria, both in teaching undergraduate microbiology and through my own research. Many bacteria have the ability to produce pigmentation, spanning the spectrum of color from dark purple to yellow. Pigments include violacein (purple), prodigiosin (red), carotenoids (orange-yellow), fluorescein (greenish-yellow), and pyocyanin (blue-green). Colorful bacteria can be isolated from many common sources, including soil, water and human skin. The frequency with which such pigmented bacteria can be isolated from environmental samples suggests that pigments must play an important role, since each pigment requires enzymatic pathways to synthesize them that can be quite complex and therefore costly. The production of prodigiosin by *Serratia marcescens*, for instance, requires more than a dozen different enzymes (Harris et al., 2004)! Have you ever wondered what function these pigments really play?

The following is an inquiry-based approach to studying pigments that can be used in diverse settings, including non-majors biology, ecology, chemistry, and physics courses as well as general microbiology classes. The above-mentioned question is an excellent starting point for having students think about science at multiple levels, including structure – function relationships, heritability and expression of biological traits, natural selection and the cost/benefit of pigment production, physical and chemical properties of pigments, and so on.

Pigment studies as an inter-disciplinary STEM project. Although the most obvious questions about bacterial pigments relate to their biological role, don't miss the opportunity to delve into inter-disciplinary ideas! Pigments are often quite complex chemical compounds composed of one or more cyclic hydrocarbon skeletons. The spectrum of light that is absorbed by a pigment (a.k.a. its absorption spectrum), and hence its color, depends on the chemical structure of the pigment, and changes to this structure can change the color. Use this pigment study to integrate concepts of organic chemistry and physics of light into your class. Likewise, the calculations of dilutions and bacterial numbers integrate math skills.

An inquiry-based learning module using pigmented bacteria

Do bacterial pigments have a purpose beyond the merely decorative? Your students are sure to have some good ideas. An open-ended group discussion is going to produce a variety of possible answers, many of which are testable in a class setting. The following sequence of hands-on activities can be adapted to your classroom setting by selecting those for which you have the time and resources available. Alternatives are suggested at each level, and detailed protocols included at the end of this article. Although students should be encouraged to come up with their own ideas, prior lessons or readings could be used to suggest some possibilities, namely that bacteria produce pigments for: 1) photosynthesis, 2) antibiotic properties, 3) UV/light protection, 4) competition/predation protection and 5) as antioxidants. Water samples often contain cyanobacteria ('blue-green algae') whose green pigmentation consists of chlorophyll.

Chromobacterium violaceum and other purple-pigmented bacteria can be isolated from water and soil samples (Agate et al., 2016), and its deep purple pigment (violacein) has antibiotic (Durán & Menck, 2001) and anti-oxidant properties (Konzen et al., 2006) and protects against predation (Matz et al., 2004). Other pigments protect bacteria from harmful photodamage (Rajagopal et al., 1997). Soil and water samples may contain *Pseudomonas*, whose blue-green pyocyanin pigment is a factor in causing infections

(Lau et al., 2004), as is *Staphylococcus aureus*' golden pigment (Liu et al., 2005). *Serratia marcescens*' prodigiosin (red) has anti-microbial, energy-spilling, and cancer-killing properties (Williamson et al., 2006; Haddix et al., 2008; Vijayalakshmi & Jagathy, 2016). Yellow, orange, pink and red pigments are common among *Micrococcus* species (Fig. 2) and may be anti-microbial or protect them from oxidants and radiation (Arrage et al., 1993; Mohammadi et al., 2012; Mohana et al., 2013; Rostami et al., 2016).

pigment	source	Color	Putative functions
Prodigiosin	<i>Serratia marcescens</i>	Red	Antibiotic, energy management
Violacein	<i>Chromobacterium violaceum</i>	Purple	Anti-microbial, antioxidant
Carotenoid	<i>Micrococcus luteus</i>	Yellow	UV absorption
Carotenoid	<i>Micrococcus agilis</i>	Red	?
Pyocyanin	<i>Pseudomonas aeruginosa</i>	Green/blue	Virulence
Carotenoid	<i>Micrococcus nishioinensis</i>	Orange	?
Staphyloxanthin	<i>Staphylococcus aureus</i>	Golden	virulence
Canthaxanthin	<i>Micrococcus roseus</i>	Pink	antimicrobial?

Table 1. Bacterial pigments and some of their putative functions. Citations are given in the text that follows.

A. Isolation of naturally occurring pigment-producing bacteria. You may wish to start by having your students culture bacteria from soil, water, or skin swabs, having students “discover” these colorful bacteria as they go along. Alternatively, many of the pigmented bacteria can be purchased from biological supply companies. You can easily isolate and grow pigment producers from soils, water, air, plants, and human skin through a simple swab inoculation or streak plating of samples on agar (Fig. 1). Once students have grown their own bacterial colonies, have them compare plates to select the most colorful colonies.

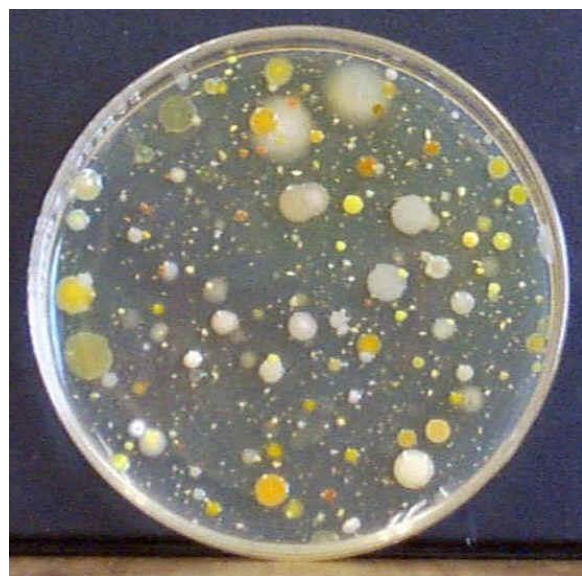


Figure 1. Bacterial colonies from a water sample growing on agar include many pigmented species.

B. Functions of pigments. Once students have the opportunity to observe colorful bacteria, you can have them come up with hypotheses about their function. Some good questions to start a discussion may be:

- How common are pigmented bacteria (as a percentage of the entire population)?
- Which colors predominate?
- Why do you think bacteria produce pigments?



Figure 2. A palette of pigmented bacteria, clockwise from bottom: *Micrococcus* (yellow, orange, pink and red), *Serratia* (dark red) and *Chromobacterium* (purple)

Although not all ideas that students are likely to come up with are testable, many can be investigated

and will make for a colorful lesson! Alternately, you can provide readings for students to explore and discuss. The summary above includes many references that can serve as a starting point.

C. Preparing pure cultures of bacteria. To study pigments, bacteria must first be grown in quantity as a pure culture; either an agar plate or liquid medium can be used. Have your class work in groups to prepare cultures of growth medium each containing a different-colored microbe. These cultures can be used to extract pigments, paint pictures on agar (Fig. 3), or study pigment functions. By observing cultures under different conditions, students can study the effect of temperature, light, or nutrients on color development. You can also freeze portions of these for future use.



Figure 3. Agar plate with bacterial growth illustrates the beauty of bacterial pigmentation

D. Extraction and analysis of pigments. Your students can now extract the pigments from the cells using solvent extraction. The solvent to be used depends on the type of pigment (Dunn et al., 2004). The extracted pigments can be analyzed with a spectrophotometer by measuring the amount of light absorbed at different wavelengths (absorption spectrum; Fig. 4). Each pigment's absorption spectrum is unique and can help identify specific bacteria (Sahin, 2011).

E. Examining pigment function in bacteria. Some of the possible roles of pigments can be studied in the laboratory with minimal resources, such as antimicrobial properties and UV light resistance. Other interesting concepts you can tie in to your lessons include quorum sensing, a phenomenon where pigment production in *Serratia* and *Chromobacterium* requires a certain cell number, or "quorum", to take place (McClellan et al., 1997; Van Houdt et al., 2007); temperature-dependent pigment production (*Serratia* produces pigment only below 35°C; competition

(many pigmented bacteria out-compete non-pigmented rivals); and predation.

F. The physics and chemistry of light and color. Interwoven with the chemical and biological aspects of pigmentation is the understanding of how light works. The visible spectrum of light consists of a range of wavelengths (400 – 700 nm) which, when impinging on a molecule, may be absorbed, reflected or transmitted. Wavelengths which are absorbed or reflected by an object determine the color that is perceived by the human eye; in the case of chlorophyll, those reflected wavelengths are predominantly green light, hence the color of most plants. In other cases, it is the complementary color of the absorbed wavelength that is seen. The chemical structure of pigments determines the wavelengths that are absorbed, and is influenced by chemical bonds, pH, and molecular size (see Clark, 2019 in the online resources section).

G. A place for math. While all of the experiments can be set up for students, don't miss the opportunity to engage them in the calculations they may need to perform. Serial dilutions are a frequent necessity in microbiology as the number of bacteria in samples often measures in the billions. Calculating dilution factors and using scientific notation are incorporated into this exercise. Analyzing and graphing data, even if done using software, builds analytical skills such as scaling, normalizing data, and comparing populations using statistical tests.

Procedure

Protocols for culturing and analyzing pigmented bacteria. Whether using bacteria for artistic or scientific experiments, here are a few protocols to get you started. Students should always practice safe laboratory techniques when handling bacteria – handle these soil/water bacteria as if they were hazardous, even if they are perfectly safe. Sterilize and dispose of all cultures properly after the experiments are done.

Materials needed for a class of 24

General: per group: Bunsen burner or bacticinerator; inoculating loops; 100 ul and 1 ml micropipettors and pipette tips; balance; weigh paper

Soil culturing: Saline solution (9 g sodium chloride in 1 L distilled water), 3 Erlenmeyer flasks (250 ml size), stoppers or tin foil, 24 Trypticase Soy Agar (TSA) plates (can be purchased pre-made), sterile screw-cap test tubes for collecting soil

Skin Swabs: 24 TSA plates, 24 sterile cotton swabs, 100 ml sterile saline or water

Lake or stream water: 24 TSA plates, sterile bottles for collecting water sample

Pure culture study: 24 TSA plates, pure cultures of *Chromobacterium violaceum*, *Micrococcus luteus*,

Micrococcus roseus, *Micrococcus agilis*, *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Rhodospirillum rubrum*, and/or *Serratia marcescens*

Spectrophotometry: 100 ml of various solvents (ethanol, acetone, methanol or isopropanol), screw-cap tubes, spectrophotometer, cuvettes. Solvents

should be selected based on availability, safety, and effectiveness. While we have found methanol to be most effective, other less toxic solvents such as acetone can also give satisfactory results (Fig. 4). Pigment extraction may be more effective at different concentrations of solvents (70 – 100%).

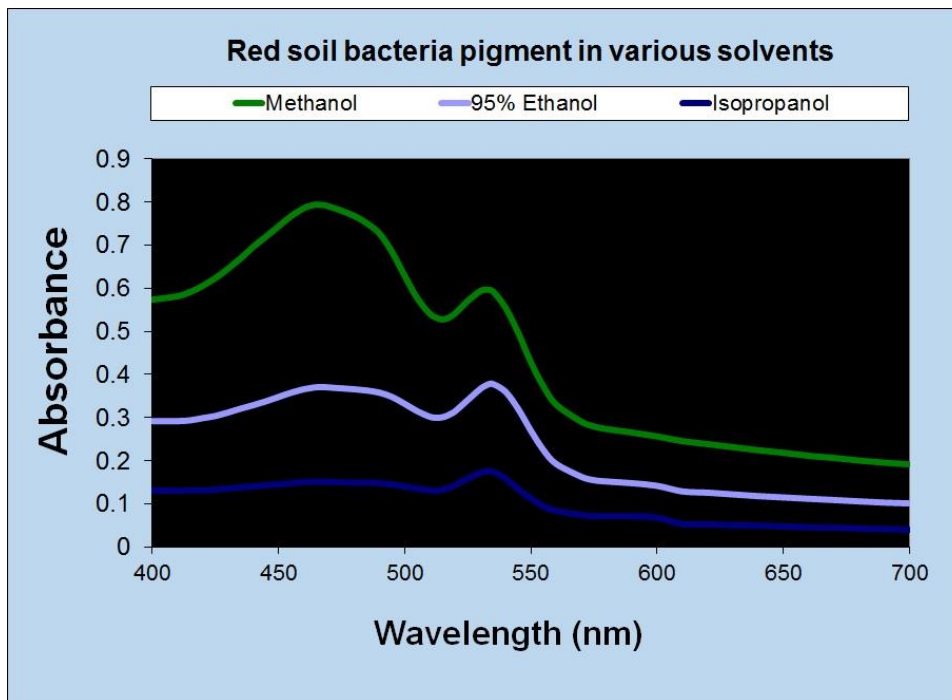


Figure 4. Absorption spectrum of pigment isolated from a red soil bacterium after extraction with methanol, ethanol or isopropanol.

Protocols

Sterilization. Sterilize all liquids and pipettes by autoclaving for 20 minutes at 121°C at 15 psi pressure. Alternately, pre-sterilized solutions and media may be purchased. Glassware can be heat-sterilized (2h at 160°C). Surfaces as well as stoppers can be adequately disinfected with 70% ethanol.

Culturing soil samples. Since bacteria are abundant in soils, a dilution is necessary to avoid having all the colonies grow into each other. Weigh out 1 gram of soil and add it to 99 ml of sterile saline solution. Stopper the flask and shake vigorously for 1 minute. Using a sterile pipette, remove 1 ml from this flask and add it to a second 99 ml flask of saline. Stopper the flask and shake vigorously for 1 minute. Transfer 1 ml from flask #2 to a third flask, stopper the flask and shake vigorously. Students now have 3 dilutions available: Flask #1 (1:100 or 10^{-2}), Flask #2 (1:10,000 or 10^{-4}), and Flask #3 (1:1,000,000 or 10^{-6}). Add 1.0 ml of dilution #3 to the surface of an agar plate and spread out the water sample using a bent (L-shaped) glass rod sterilized in ethanol or boiling water. The agar plates should be taped shut and allowed to incubate at room temperature for 2 – 7 days.

Culturing water samples. Most lake, pond or stream samples contain far fewer bacteria per ml than soils, and 0.1 – 1.0 ml of the water sample can be placed directly onto the surface of an agar plate. Samples are spread out and incubated as noted above.

Culturing skin bacteria. Moisten a sterile cotton swab by dipping it into a beaker of sterile water or saline solution. Vigorously rub the swab over a 2 cm x 2 cm area of skin (forearm works nicely) and, with gentle pressure, rub and roll the swab over the surface of a TSA plate. Incubate 2 – 7 days at room temperature.

Culturing commercial strains of bacteria. *Chromobacterium violaceum*, *Micrococcus luteus*, *Micrococcus roseus*, *Micrococcus agilis*, *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Rhodospirillum rubrum*, and *Serratia marcescens* can be purchased from Biological Supply companies such as Presque Isle Cultures (Erie, PA). These cultures will be shipped in agar slant tubes and will be ready for use. Aseptic transfer of bacteria to the agar plate is done with inoculating loops. Metal loops are heated (Bunsen burner or bacticinerator) for 10 seconds to sterilize them before and after transfers. Alternatively, pre-sterilized plastic loops can be purchased and

disposed of when done. The bacteria picked up with one loop are sufficient for an experiment. Transfer the bacteria to their agar plate and coat from ¼ to ½ of the agar plate surface with each strain selected. Incubate the plates for 2 – 7 days at room temperature.

Producing pure cultures from environmental samples. Once the individual colonies of bacteria from soil, water, or skin have grown to a size of 1 – 5 mm (see Fig. 1), select one colony of interest. Describe the colony (color, size, shape). Using an inoculating loop, carefully transfer part of the colony to a sterile agar plate as described above. Incubate for 2 – 7 days at room temperature. After incubation, examine the plate carefully to ensure that only the desired bacteria are growing on this plate.

Painting with bacteria. For each “color” (pigmented bacterial strain) and group of students, add 10 ml of 0.9% saline to sterile screw-cap test tubes. Using a sterile inoculating loop, add 3 loops of a pure bacterial culture (bought or prepared as described above) to a tube, tightly seal the tube with the screw cap and shake well to mix. You may wish to prepare larger volumes to divide up your stock into test tubes for several lab groups to use. Label flasks and tubes. Allow each student to ‘paint’ on a sterile agar plate using two or more ‘colors’. Remind students to use a different loop for each culture. Seal each agar plate with tape and incubate the plates for up to one week at room temperature. At the end of the class, collect bacterial culture flasks and tubes and sterilize. Particularly creative artwork can be submitted to the annual Agar Art contest (see online resources).

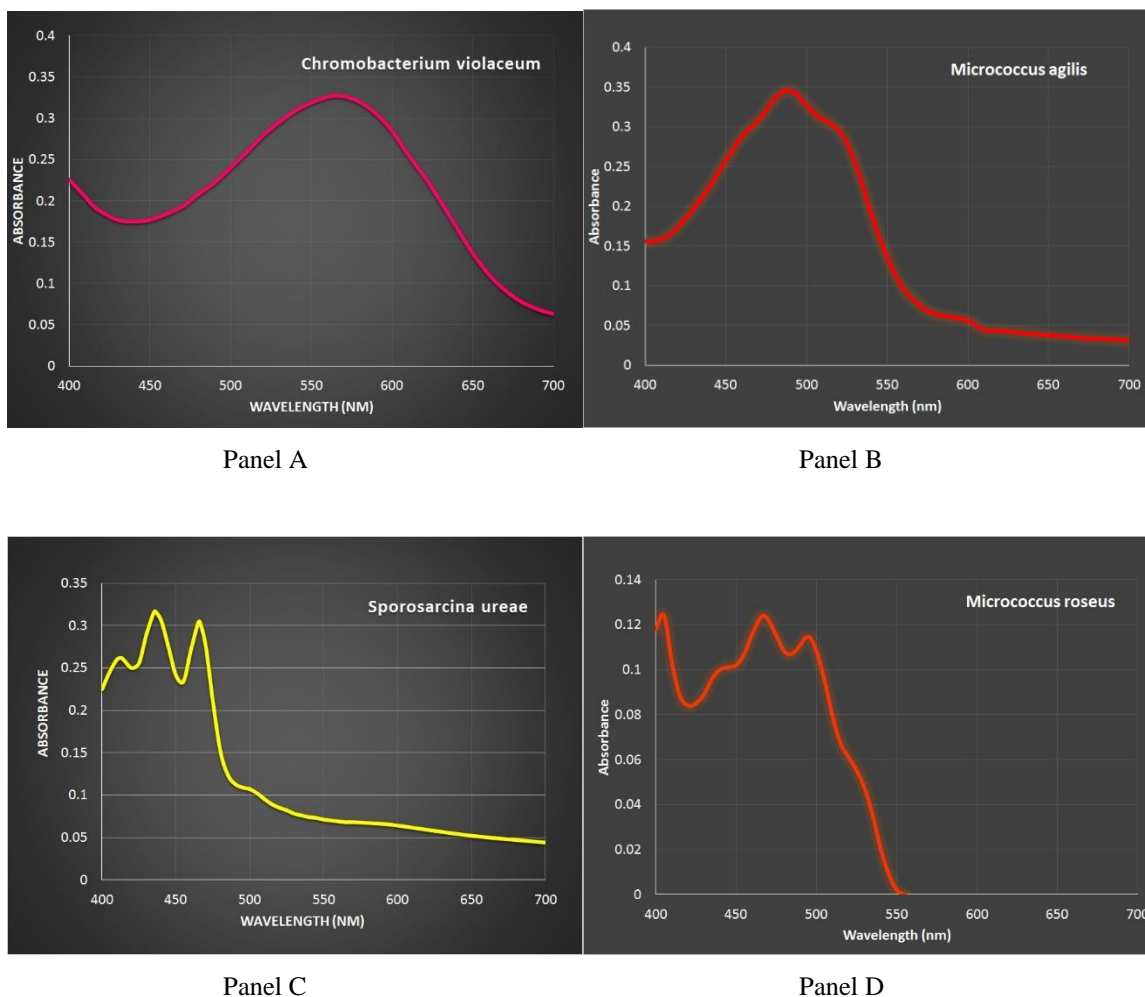


Figure 5. Absorption spectra of pigments isolated from *Chromobacterium violaceum* (A), *Micrococcus agilis* (B), *Sporosarcina ureae* (C) and *Micrococcus roseus* (D).

Spectrophotometry. Add 5 ml of solvent to a sterile screw-cap tube. Solvents should be selected based on availability, safety and disposal considerations, and effectiveness (often based on the lipid solubility of the pigment). Suggested solvents include acetone (80% or 100%), ethanol (70%, 95% or 100%), methanol (100%), or isopropanol (70% or 95%). Once sufficient bacterial growth is observed on the pure culture plate, transfer a pea-sized clump of cells (~1 g) of the culture into the solvent by scraping the agar surface with a sterile inoculating loop. Several loop transfers may be necessary. Cap the tube and shake or vortex (if a vortexer is available) for 5 minutes until the pigment is well dissolved in the solvent. Water-soluble pigments will easily dissolve in alcohols, but lipid-soluble pigments may require chloroform, benzene or other non-polar solvents. Additional disruption of cells may help release pigment, including mashing the cells with a mortar or using sonication. Turn on the spectrophotometer 15 minutes before taking measurements. Follow the manufacturer's instructions for calibrating and using the instrument. Most spectrophotometers accept 13 mm x 30 mm cuvettes. One such cuvette should be filled with pigment-free solvent used in the extraction. This cuvette can be shared among lab groups and is used to calibrate the baseline (zero) absorbance before each reading and at each wavelength. Take the first absorbance reading at the lowest wavelength allowed by the instrument (usually ~350 nm) and take readings in increments of 10 nm, up to the maximum of ~700 nm (Fig. 5). Some instruments will automatically scan the entire spectrum, allowing more rapid data collection. If compatible with data collection software such as LoggerPro, data will be saved and graphed automatically. Other skills that can be practiced here include graphing, comparison of the spectra of several different-colored bacteria, and normalizing data relative to each spectrum's maximum value. This will allow students to understand the difference between absorbed and reflected light and to better discuss the role of pigments in biological process such as photosynthesis.

Further studies

Although brief in nature, the following ideas can easily be adapted to your classroom setting, and we have tested and tried these ideas already.

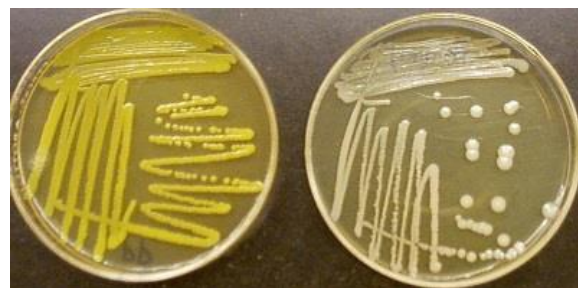
Antibiotic properties. A simple test of the antibiotic potential of the pigment can be carried out using the Kirby-Bauer method (Bauer et al., 1966) with the pigment extract. Transfer 5 ml of the pigmented solvent to a clean test tube. Place 6 small paper disks (I use the cardboard backing from notepads and a single hole-punch, then sterilize the disks in an autoclave) into the tube and allow the solvent to evaporate – this may take several days. Place each dried paper disk on an agar plate inoculated with

Escherichia coli or *Staphylococcus aureus* and observe the plates for the absence of growth around the paper disk. Suitable controls should be conducted with solvent-exposed disks.

Study of pigment-less mutants. The importance of the pigments can be further studied by using non-pigmented mutants. Pigmented bacteria are suspended in 10 ml of 0.9% NaCl and then exposed to UV light for 1 – 5 minutes. 1,000,000-fold dilutions are spread on Petri plates and cultured in an attempt to find non-pigmented mutants. Using this approach, we were able to isolate mutant strains of *M. roseus*, *P. putida* and soil bacteria (Fig. 6). Such mutants can also be used in a genetic analysis of the pigment-synthesizing pathways (Schmidt, 1993). Non-pigmented mutant strains are also available from researchers who are often willing to provide such cultures for teaching purposes, and some bacteria (e.g. *Serratia*) will be non-pigmented at temperatures above 35°C.



Panel A



Panel B



Panel C

Figure 6. Pigmented bacteria and non-pigmented mutant strains obtained by UV exposure. (A) Red soil bacteria (unidentified), (B) *Pseudomonas putida*, (C) *Micrococcus roseus*.

Protection from UV light or chemicals. To evaluate the importance of pigmentation in protecting bacteria from oxidative stress, UV radiation or other challenges, pigmented and unpigmented strains of the same species can be subjected to UV light (Fig. 7),

ozone (de Ondarza, 2017), hydrogen peroxide or antiseptics/disinfectants. This experiment will require good dilution skills and enumeration of surviving bacteria.

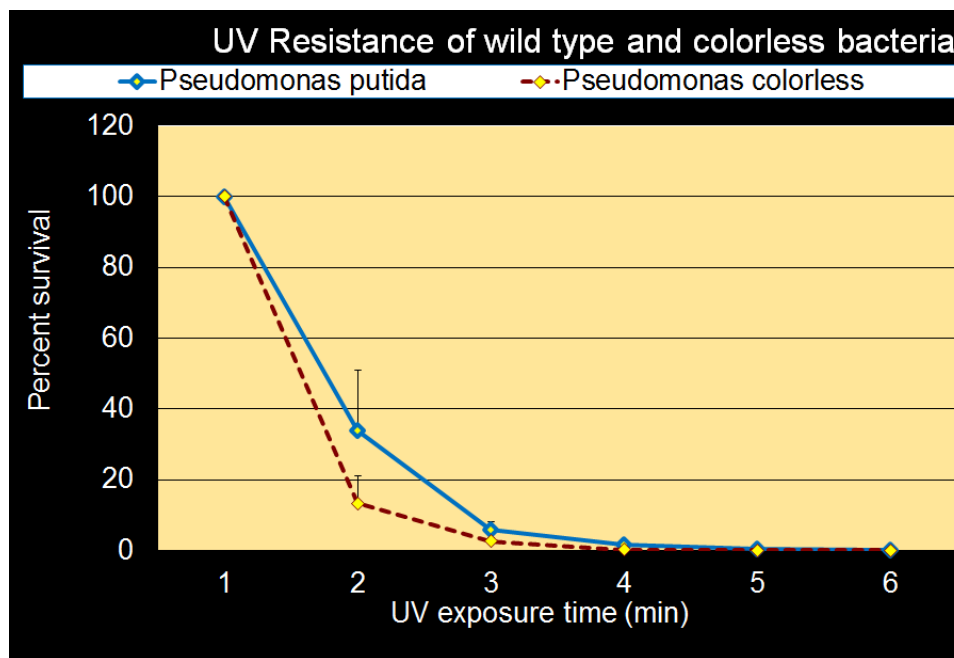


Figure 7. Effect of UV irradiation on survival of pigmented and non-pigmented (mutant strain) bacteria.

Safety considerations. The bacterial strains selected for this study are generally harmless to human health. Nonetheless, many bacteria are opportunistic pathogens and may cause an infection if in contact with a scratch or open wound. Students should handle all bacteria with the utmost caution. Lab benches should be disinfected before and after class with commercially available disinfectants. Students should wash their hands and wear protective gloves, lab coats and goggles. Absolutely no mouth pipetting, eating or drinking should be allowed.

Disposal. All biological materials and disposable objects that came in contact with them (agar plates, plastic pipettes, plastic loops, paper towels, filter paper) should be disposed of in a large biohazard bag. Seal the bag and sterilize by autoclave. (Other arrangements may be available to you for the safe disposal of biohazard materials). Disposal of solvents usually requires special arrangements, such as flammable waste containers.

Discussion

As science and scientific research become more specialized and focused, we often miss out on the inter-disciplinary nature of most biological studies and experimentation. By designing projects to intentionally include lessons in other disciplines such as physics, chemistry and ecology, students can be

engaged in multiple ways while gaining a deeper understanding of the ways different STEM disciplines interact. Some of the most insightful ideas in my classroom have come from students outside of the traditional Biology curriculum, including art, education, history, nutrition and physics. Bacterial pigments are ideally suited to such inter-disciplinary projects; they are at once visually enticing and generate curiosity. Bacteria that produce pigments are readily isolated from natural habitats such as soil and water and even the human body and can be cultured with very little material and equipment. The potential to engage students in “living art” through painting pictures on agar plates is stunningly illustrated by the many entries into the annual Agar Art contest of the American Society for Microbiology. Pigments from bacteria are extracted with minimal difficulty or expense and allow for further study of their possible function. Mostly, having students discuss the “why” of bacterial pigments engages them in the physics of light absorption, the energy cost of biosynthesis, the potential selective advantage of a biological trait, the ecological interactions (predation, antibiosis) involved, and the chemistry of complex pigments. A learning module that incorporates lessons in physics, chemistry, biology and ecology can be implemented over a 3-4-week span in one class or even engage instructors and courses outside of biology in a common-problem project.

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Using Student-generated Press Releases in a Vertebrate Physiology Course to Enhance Scientific Communication Skills

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Abstract: This article describes an activity designed to hone students' lay communication skills. After carefully analyzing journal articles that highlight specific aspects of vertebrate physiology, students generate "press releases" to summarize experimental results and suggest potential applications of the research. By producing succinct, jargon-free summaries of current research, along with creative connections between the research and potential real-world applications, students develop skills that allow them to communicate more effectively with the general public.

Key words: Press releases, communication skills, primary literature

Introduction

Davis & Elkins College (D&E) is a small, private liberal arts college that emphasizes small class sizes and strong faculty-student interactions. In the Department of Biology and Environmental Science, students are introduced to the critical analysis of primary scientific literature as early as the sophomore year, and the importance of data interpretation is stressed throughout the curriculum. By the end of the senior year, we expect our majors to be able to interpret scientific data and assess the merit of published research according to evidence presented.

While the ability to analyze primary literature is critical, it may not be sufficient to prepare students for interactions with the lay public. According to Millar and Osborne (1998), one of the necessary outcomes of formal science education is the ability to "understand, and respond critically to, media reports of issues with a science component." Misconceptions regarding vaccinations, genetically modified organisms, and climate change abound. Scientists, current and future, need to address these misconceptions. What can be done to reduce the epistemic distance between scientists and the public? The answer may be communication. Scientists need to communicate information to non-scientists in a way that is understandable, but not condescending.

Vertebrate Physiology is an elective course for biology majors at D&E. The course surveys physiological mechanisms common to all vertebrate animals and introduces functional adaptations essential to each vertebrate class. The course is divided into five sections: respiration, metabolism, temperature regulation, osmotic regulation, and biomechanics. The laboratory portion of the course incorporates analysis of current research articles from the primary literature, typically one paper per section. In recent years, in addition to standard analysis of research data, I have required students to generate "press releases" that summarize experimental results

for the general public. The press release is more than just a filtered abstract. It is meant to spark interest in readers, to inform readers of recent scientific efforts, and to demonstrate how the research might potentially affect readers. Generation of a good press release requires some creativity, distinct from standard scientific writing.

Assignment

The assignment begins with the formal analysis of a journal article, using very specific guidelines (Table 1). Subsequently, students are instructed to generate a jargon-free summary of the paper that would be appropriate for non-scientists. They are then tasked with making that summary appealing to the general public by turning it into a short press release that includes potential real world applications of the published research. Press releases are read aloud in class, and students collectively decide which one(s) would most effectively engage a non-scientific audience. See Table 2 for an example of an effective press release.

In 2015 and 2018, the last two times I taught the course, I used the same five research articles to highlight the five distinct physiological sections. The respiration paper specifically dealt with pulmonary gas exchange in foxhounds after high-altitude residence during maturation (McDonough et al., 2006). Blood volume, lung function at rest, and lung function during exercise were measured, and the authors concluded that short exposure to high-altitude during maturation improves long-term lung function into adulthood. In their press releases, many students linked the research outcomes to potential impacts on human athletic training, including the dominance of Kenyan distance runners and the placement of the U.S. Olympic Training Center in Colorado Springs, CO.

The metabolism paper described the effect of high incubation temperatures on energy metabolism in softshell turtle embryos (Sun et al., 2015). The

Component	Description
Citation	Author's last names and first initials, year of publication, title of article, name of journal, volume number, issue number, first-last page numbers.
Knowledge Gap	What biological question does the research address? In other words, what was known and unknown prior to this research? What is the significance of the current study? This information is generally found in the Introduction.
Overall hypothesis	A statement of explanation regarding the research question. A hypothesis may not be clearly stated. It may have to be inferred based on the procedures used to address the research question.
Prediction	An "If..., then..." statement. If the hypothesis is supported, what results are expected?
Methods	What was measured or determined? Summarize the approach in your own words.
Results	What new information was produced? Summarize the results in your own words.
Conclusion	What do the authors make of the data? Are their conclusions valid? Do the data support the hypothesis? Is there any other possible interpretation?
Future studies	A good paper may generate more questions than it answers. What is the next question researchers in the field should address?

Table 1. Instructions for analyzing journal articles (based on an instrument created by Dr. Catherine Gardiner, University of Northern Colorado).

authors isolated mitochondria and assayed metabolic enzyme activity, concluding that embryos can adjust mitochondrial respiration and enzyme activity in response to developmental temperature. Several student press releases considered the impact of global warming on turtle populations, while others focused on potential conservation efforts in zoos and wildlife refuges.

The temperature regulation study investigated muscle oxygen consumption at low temperatures in frogs of the genus *Xenopus* (Seebacher et al., 2014). After isolated muscle mechanics and oxygen

consumption were analyzed, it was concluded that the metabolic cost of muscle performance increases as temperature decreases. Most students immediately saw the application to human athletic performance. They focused on the benefits of warming up muscles prior to competition, especially in cold weather.

The osmotic regulation article addressed the adrenocortical stress responses of invasive cane toads in a desert environment (Jessop et al., 2013). Researchers recorded the effects of hormone manipulation on the toads' stress responses, dehydration levels, and survival rates. Ultimately, they

With global warming on the rise, it is natural to assume that some species are being negatively impacted. Wei-Guo Du and colleagues studied turtle eggs incubated at low, medium, and high temperatures. They found that eggs incubated at higher temperatures were better at maximizing oxygen intake and efficiently using it to make energy. As the temperature increased, so did the eggs' metabolic rates. These results suggest that turtle embryos incubated at higher temperatures may actually have an advantage. However, the study also indicated that hatchling turtles that were acclimated to lower temperatures had a more efficient metabolism than those acclimated to higher temperatures. While global warming may not adversely affect turtles at the embryonic stage, it could still produce metabolic consequences after they leave the comfort of their eggshells.
Before competition, athletes are advised to take time to warm up their muscles, especially in colder conditions. Most athletes know that it helps to prevent a pulled muscle, but they may not know that it can actually improve the energy efficiency of their muscles. Lower temperatures increase the tension in muscles, making it more difficult for contraction. Seebacher and colleagues studied the relationship between temperature and muscle power in frogs of the genus <i>Xenopus</i> . They measured speed, muscle contraction/relaxation time, oxygen consumption, and power generated. They then used the data to calculate the energetic cost of work at cold and warm temperatures. They found that the total cost to perform the same amount of work is much higher at colder temperatures than at warmer temperatures. Frogs at lower temperatures required more oxygen, generated less power, and exhibited lower speeds. Athletes could experience similar results if they do not properly warm up their muscles prior to competition in cold weather.
Malaria is a life-threatening disease that is carried by mosquito vectors in certain hot climates, like those found in sub-Saharan Africa. One way to decrease the number of malaria infections is to decrease the vector population. This might be done by introducing an invasive species of mosquito predator, like frogs or toads. However, introducing a species to a new environment may fail if the species is unable to adapt. Amphibians can be susceptible to desiccation in hot environments. A study conducted by Tim Jessop and his colleagues demonstrated that cane toads (<i>Rhinella marina</i>) have adapted a mechanism to reduce water loss and overheating in the hot-dry climate of Australia. Although the exact pathway is still unclear, the researchers found that these toads have regulated their stress response hormones in a way to prevent desiccation and overheating in the harsh climate. The experimental groups of toads, which had their stress hormones either upregulated or downregulated, were far less successful than the unaltered toads. Since these toads have begun to adapt to the hotter climates, they could prove to be an effective new predator for malaria spreading mosquitoes.

Table 2. Press release examples.

determined that adrenocortical hormones reduce evaporative water loss and increase survival. Some students saw an opportunity to combat malaria in sub-Saharan Africa by dispatching an army of dehydration-resistant cane toads to prey on mosquito vectors. While the introduction of an invasive species can potentially be disastrous, it suggests that students were thinking creatively.

Finally, the biomechanics study examined the potential connection between incline running in galliform birds and the evolution of flight (Dial, 2003). Adult birds, fully capable of aerial flight, employed wing-assisted incline running to reach elevated refuges in both natural and laboratory settings. The author indicated that the specific angle of the wing-stroke generated aerodynamic forces oriented toward the substrate to enhance hindlimb traction. Students gravitated to the notion that incline running may have been practiced by feathered dinosaurs, an idea suggested by the author, leading to the gradual

evolution of flight in birds. A few students suggested clever applications for robotics, including a winged window-washing robot, based on the aerodynamic and inertial forces associated with the wing-stroke cycle.

The Vertebrate Physiology course historically has a small number of students, usually fewer than 10. The last three times I taught the course, in 2012, 2015, and 2018, I conducted an informal survey of students to assess the value of the press release activity. Of the 21 total responses I received, 19 were very positive, often describing the activity as being “fun,” “interesting,” or “a great way to keep us thinking about physiology” (Table 3). The only two negative comments came in 2012, when some of the research articles I assigned to illustrate physiological adaptations involved the use of human subjects. The dissenters were pre-veterinary students who indicated that they had signed up to focus on non-human vertebrates. It was a good point. We have a separate course in Human Physiology.

“I enjoyed the press release exercises. They really helped me understand the relevance of the research.”
“Writing press releases forced me to think about the potential impact that scientific research can have.”
“Research articles can be difficult to read and comprehend. Considering the practical aspects of the work makes it seem much more interesting and relevant.”
“Reading the research papers demonstrated to me the type of work being done in the field of animal physiology. Writing the press releases allowed me to consider the potential applications of the work.”
“Writing for the general public is much more fun than writing for lab reports. It’s also a great way to keep us thinking about physiology and the impact it has on everyday life.”

Table 3. Comments from students.

We remain committed to our emphasis on primary literature in the department. The ability to dissect a journal article, interpret its results, and assess its merit, is an absolute necessity for biology graduates. However, we are also committed to improving our students’ communication skills. We want them to be able to communicate with the general public, as well as the scientific community. Vertebrate Physiology students have demonstrated that they can generate succinct, jargon-free summaries of current research. Furthermore, due to the creative connections they make between current research and potential applications, their press releases are interesting, insightful, and relevant to lay readers.

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Linking Phrases for Concept Mapping in Introductory College Biology

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Abstract

Concept maps can be used in undergraduate biology as ways to visually communicate the relationships among things and events. One strength of concept mapping is that there is not just a single, correct way to compose one, given a list of particular concepts. Nevertheless there seem to be associations among ideas that are expressed frequently while teaching biology. For example, hierarchical relationships among structures and steps within processes are two common kinds of relationships that students encounter regularly. Based on our own classroom experiences and surveys of concepts appearing in two popular textbooks, we provide here a resource for composing propositions within biological concept maps. This list of more than 50 linking words and phrases is appropriate for freshman biology but can be adapted for use in more advanced courses.

Keywords: Mind maps, college science education, logical relationships

Introduction

The types of courses taken by a first-year undergraduate are usually formal introductions to particular scholarly disciplines. Success in such courses is required to then proceed to more advanced courses within that particular major field of study. However, these courses can act as veritable academic minefields to students, and are often referred to as gatekeeper or weeding-out courses because they frequently result in students doing poorly (and thus requiring a repeat term in the course), switching majors, or withdrawing from higher education altogether.

The issue of gatekeeper courses is especially acute for STEM majors. Whether the time spent until entry into a STEM career is referred to as a pathway, pipeline (Shaw et al., 2012; Allen-Ramdiel & Campbell, 2014; Miller & Wai, 2015), or other metaphor, such experience involves a variety of factors that can either retain or repel students from the discipline. In some cases lack of success in an introductory STEM course (including required STEM courses outside of one's own STEM major) could determine whether a student continues to pursue any STEM career whatsoever. Decisions to abandon a STEM major may thus be based on the perceived rigidity of curricula and difficulty of courses within it. In other words, the timing and sequence of courses within a degree program do not allow a student to graduate "on time" if he fails any one particular course. (For the sake of brevity, we will not address here what constitutes an appropriate amount of time to complete degree requirements.) Another, related factor that may enter a student's decision-making process about whether to pursue a STEM degree has to do with what has been called the "push-pull" of majors. That is, majoring in a STEM discipline can be

perceived as more difficult, less interesting, or otherwise less rewarding than majoring in a non-STEM discipline. The connection between introductory courses and the push-pull of majors was highlighted by Chambliss and Takacs (2014), who observed that a student's experience with her first professor in an academic discipline (e.g., an instructor of an introductory course) had a notable effect on whether that student decided to stay within that major.

The high vocabulary load of introductory biology courses may be a barrier to student success and may, in turn, have several contributing factors. One has to do with choices by individual professors to include more vocabulary than is absolutely necessary to attain their teaching goals and their students' concordant learning outcomes. Instructors' choices, in turn, may be driven by textbooks and their publishers' decisions to increase the amount of included jargon over time, to achieve a sense of up-to-date rigor. Biology's "terminology problem" does not seem to be waning and Wandersee (1988) observed that the field's ongoing proliferation of acronyms, terminology incorporated from chemistry, polysyllabic words of Greek and Latin origins, terms with multiple conflicting meanings, and new terms coined by empirical researchers all contribute to overwhelming and stifling the interests of nascent biology students.

Wandersee (1988) cited both Ausubel (as Ausubel et al., 1978) and Novak (1977) in his recognition of the weakness of rote learning (verbatim memorization) of biological terminology, and advocated for careful selection by professors of the terminology to be learned meaningfully by their students. In contrast to rote learning, meaningful learning allows for future learning of related concepts such that they can be subsumed into an individual's extant framework of knowledge (Ausubel, 1963, 1968). Drawing upon the

work of Ausubel (1963, 1968), the development of concept maps (as described by Novak, 2010) was firmly intended to result in meaningful learning. Associations among biological terminology, concept mapping, and meaningful learning have thus been recognized (Wandersee, 1988) for at least three decades.

Ultimately, satisfaction with and, presumably, success in a course seems dependent upon whether a student felt engaged by the professor. Student engagement takes on various forms, not only within the spatiotemporal confines of a particular course, but also across the college experience as a whole. Active learning (Freeman et al., 2014) and student engagement often mentioned in the same work, and it can be argued that “active” and “engaged” are synonymous (Chi & Wylie, 2014) or that active learning is the process through which student engagement occurs. Course-based undergraduate research experiences (CUREs; Bangera & Brownell, 2014) and flipped classrooms are examples of two popular strategies designed to increase student engagement and, in turn, student success. Another active learning strategy is concept mapping, which was originally developed by Novak in the 1970s (Novak & Cañas, 2008). In contrast to CUREs and flipped classrooms, which might be categorized types of course formats, concept mapping is a type of course activity that is compatible with almost any type of course format.

Concept maps are similar in design to figures such as mind maps and argument maps: all are ways to express relationships among ideas. Davies (2011) compared and contrasted the three, concluding that they indeed represent distinct communication strategies with each having advantages and disadvantages. Concept mapping, as envisioned by Novak (2010), involves creation of a network of concepts that together help answer a focus question, describe a more encompassing topic, or otherwise establish what a particular set of concepts have to do with one another. Within a concept map, a pair of concepts is joined by a linking word or linking phrase, such that a proposition is formed. Linking phrases are typically only one to five words in length so the whole proposition communicates, in a manner akin to telegraphic language, the relationship between the two concepts. Each proposition has polarity or directionality, indicated by an arrow that joins the two concepts and near which the linking phrase is written. This directionality can be critical to the meaning of a proposition. For example, it would be factually correct for a proposition to indicate that “toe is part of foot” but it would incorrect to state, in the opposite direction, that “foot is part of toe.” Similarly, an incorrect proposition such as “ATP produces glycolysis” could be modified to instead correctly assert that “glycolysis produces ATP.”

Concept maps are similar to outlines in summarizing larger bodies of text or knowledge. An outline uses features such as subordination and division to portray logical relationships among its components. In concept maps, subordination can also convey hierarchies of ideas. These relationships can also be rendered in even more revealing ways in a concept map with explicit cross-links that are not easily gleaned from an outline, since each concept in a concept map may have multiple arrows leading to and from it, forming multiple propositions, which collectively express a meaningful body of knowledge.

Each proposition has the form concept-linking phrase-concept. An experienced concept mapper is able to effectively form propositions using appropriate linking phrases, organize concepts in a hierarchical manner, and provide cross-links (i.e., form propositions connecting different “regions” of the concept map) among related concepts (Mintzes et al., 2011). Rote learning, argued Ausubel (1968) and Novak (2010), contrasts with the meaningful learning that concept mapping ideally represents. The former is what instructors should not encourage in their own classroom activities or assessments. Rote learning, however, is unfortunately the default strategy for many students. It often takes the form of memorizing definitions to vocabulary terms (i.e., concepts) without real demonstration of how such terms are related. Encouraging students to map a given set of concepts, either as a formative or summative assessment, allows them an opportunity to struggle with (and therefore meaningfully learn from) how to briefly and accurately express, in the telegraphic language of propositions, what they know about a biological topic.

Methods

We contend that concept mapping is a strategy appropriate for introductory college biology, among other types of courses, and that our included list of linking phrases is useful for potentially increasing rates of student success in such courses. This list (Table 1) was compiled through reflection upon our own teaching and research experiences in biology, and extracting from them the kinds of phrases and verbal collocations that we perceive to be used frequently. We also inspected the glossaries of two introductory textbooks that have national distribution (Russell et al., 2014; Urry et al., 2016). Each glossary entry’s part of speech (e.g., noun, adjective) was determined. Percentages of nouns, verbs, and adjectives were then calculated to quantify the relative importance placed by textbook authors upon the different kinds of biological concepts (i.e., things, actions, descriptors) in their texts. These data, in turn, helped ensure that our linking phrases that would be appropriate for propositions incorporating common concepts from introductory college biology.

adjacent to	affected by	always higher than
analogous to	approaches	approximates
argued for, against	as in	assume(s)
attracted by, to	become(s)	bound to
calculated by	cause(s)	characterized by, using
combines with	composed of	connected to
consists of	constant when	constrain(s)
contain(s)	contrasts with	converted to, via
cycles through	decreased during	derived from
determine(s)	develop(s) within	developed method(s) for, to
discovered	doesn't affect	enable(s)
enter(s)	equal to	equation for
evidence of	exclude(s)	exit(s)
expressed by	evolved in, into, during	for example, e.g., such as
forms	found in	function(s) in, to
has rate called	homologous to	in other words, i.e., that is
in units called	increases with	indicated by, with
influence(s)	inherited by	inhibit(s)
inversely proportional to	is absence of	is, are not same as
join(s) with	likely when	limited by
means flow of	measure(s)	modify(-ies)
needed for	negative when	never higher than
occurs before, after, during, until	opposite of	part(s) of
pass(es) through	perform(s)	persist(s) when
possess(es)	proceed(s) without	produce(s)
proportional to	quantify(-ies)	randomly change(s)
realized that	receive(s)	related to
repels	require(s)	result of
results in	rises exponentially with	rises non-linearly with
serves to	smaller than	special case of
split(s) into	stimulate(s)	stops if, when
stored as	strengthens	subset of
substrate(s) for	supported by, with	surround(s)
symbolize(s)	synonymous with, same as	transfer(s)
transported by, to, from	type of	undergo(es)

Table 1. Alphabetical list, in horizontal rows, of example linking phrases for use in biological concept maps. Included are phrases that occur commonly in introductory college biology. Note that some standalone words in the list can be linguistically changed into phrases and vice versa. For example, the word “stimulates” can be converted into the phrase “stimulated by.” However such conversions should be used cautiously during construction of concept maps, as they can substantively change the meanings of propositions (e.g., “X stimulates Y” contradicts “X stimulated by Y”).

Some standalone words in the list can be linguistically integrated into phrases and vice versa. For example, the word “stimulates” can be converted into the phrase “stimulated by.” However such a change can inadvertently reverse the directionality of a proposition if not done judiciously (e.g., “X stimulates Y” does not hold the same meaning as “X

stimulated by Y”). Thus the use or substitution of a particular preposition within a proposition can alter its meaning. Notice also the differences in meaning of “transported to” and “transported from.” Given this linguistic flexibility of the 105 linking words and phrases provided in Table 1, we conjecture that many more can be easily derived from those given.

Discussion

Introductory undergraduate biology is rife with specialized vocabulary, and courses for similar audiences in chemistry, physics, and mathematics also rely on specialized vocabulary along with hosts of symbols, all of which can infiltrate introductory biology. Novak (2010) would consider all of these terms, symbols, and other ideas to be concepts, which can be learned by concept mapping. He described typical concepts as being either “things” or “events.” In the context of biology, things include anatomical structures, famous biologists, techniques, theories, or types of molecules, whereas events might include biological processes like meiosis or speciation. (In a sense, biological processes are thus both “things” and “events.”)

Interestingly, biological vocabulary seems to favor noun forms rather than verb forms (for example “photosynthesis” as opposed to “photosynthesize”). Even less emphasized in introductory biological vocabulary are adjectives (e.g., photosynthetic), though all of these parts of speech play critical roles in biological discourse. Our cursory analysis of two widely used introductory college textbooks (Russell et al., 2014; Urry et al., 2016) reveals that, in each case, less than 3% of glossary entries are adjectives. The remaining terms are almost exclusively nouns. We have not investigated, however, whether instructional emphasis on the noun, verb, or adjective form of a concept has a differential effect on learning introductory biological vocabulary.

In general concept maps can include any part of speech. However, given the proclivity for biological concepts to be emphasized as nouns, propositions within biological concept maps are likely to link either two nouns with a linking phrase (a noun-noun proposition), link a noun and an adjective (a noun-adjective proposition), or link a noun and a verb (a noun-verb proposition). Propositions involving other parts of speech (noun-adverb, adverb-adjective) are assumed to be even less frequent in biology. Thus the linking phrases listed here are probably most appropriate for propositions that include at least one concept that is a noun. Most contain either a verb or both a verb and preposition, since the object of a preposition is also a noun. The linking phrases presented here include many that are formatted to accommodate concepts that are either singular or plural nouns, to allow subject-verb agreement (for example, “affect[s]”) within propositions.

Experts can relate concepts to one another in succinct ways that novices cannot. That is, novices sometimes struggle to express deep knowledge in the propositional format required for concept mapping. For example, if a student were asked to link the biological terms cristae and mitochondria, he might

respond by formulating a proposition that reads “cristae relate to mitochondria.” While this proposition is true, it would be more meaningful if it also indicated how exactly cristae are related to mitochondria. Thus, propositions asserting that “cristae part of mitochondria” or “cristae found in mitochondria” are true statements that simultaneously describe the conceptual (here, structural or spatial) relationships between cristae and mitochondria. The linking words or linking phrases provided herein are some of many that students can use in their own concept maps. This list includes linking phrases that describe quantitative, structural, temporal, and other kinds of relationships that exist among the biological concepts commonly taught in introductory biology. As students become more confident in the mechanics of concept mapping and become more experienced using linking phrases that convey meaningful relationships (such as those supplied here), they can begin to craft their own linking phrases that also do so. In the absence of such examples, a concept mapper may remain as a novice, composing only vague (even if true) propositions. An instructor might interpret such hardship to mean that the student has not grasped the mechanics of concept mapping, does not understand the relationships among particular concepts, or both.

Linking phrases, as components of propositions, help elucidate the “who, what, where, when, why, and how” of biological ideas and interrelationships among them. While each concept can represent a standalone thing or event, the linking phrase better places it in context. Linking phrases hold explanatory power for describing the timing, duration, location, function, cause, effect, or mechanism of an event. They can also be crafted to specify whose ideas influenced or conflicted with whose, what characterizes particular structures or groups of organisms, and how certain data are collected. In short, propositions constructed with appropriate linking phrases can express the kinds of ideas that are commonplace in introductory college biology. Individuals often possess more information than they can easily express. The list of linking phrases provided here may help students and faculty unlock this tacit knowledge (Polanyi, 1966) so that it can be codified, refined, or preserved using concept maps.

As undergraduate biological education continues to undergo reform, and as instructors continue to find value in it for teaching or assessment, concept mapping may be used more extensively. It can be noted, for instance, that concept mapping remains compatible with all of the biological core concepts (evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems) and core competencies (ability to apply the process of science, use quantitative reasoning, use modeling and

simulation, tap into the interdisciplinary nature of science, communicate and collaborate with other disciplines, and understand the relationship between science and society) promulgated by Vision and Change: A Call to Action (AAAS, 2011) . As also mentioned above, concept mapping can be integrated into almost any kind of biology course format, including online courses, hybrid courses, CUREs, and flipped classrooms.

Corpus-driven analyses (sensu Biber, 2009) of introductory biology textbooks, edited volumes, and journal articles may provide quantitative insight into the kinds of phrases that describe the logical relationships among natural phenomena (i.e., biological concepts). Through identifying common patterns of how professional biologists communicate ideas to one another, we may better understand how to effectively explain new ideas to our own students. By modeling and working with concise, factually correct propositions in concept maps, we can train our students to maximize their explanatory power in the academic discourse of biology.

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Perspectives

Why Teach Biology If It Is Rejected? How to Teach Evolution So That It Can Be Accepted

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Abstract

There exists a disconnect between instruction about biological evolution and acceptance of evolution by students. This disconnect prevents students from applying the theory to their lives or to their understanding of the field of biology. We examine the literature for common barriers to the acceptance of evolution, correlates with acceptance of evolution, and potential means by which education might result in increased levels of acceptance among students. We find that by changing the way that teachers themselves are taught, and by altering the methods teachers use to teach, it is likely that student acceptance of evolution can increase from instruction.

Keywords: Evolution, Education, Instruction, Acceptance, Teaching

Introduction

Biological evolution is the central organizing theory of the field of biology [Dobzhansky, 1973; American Association for the Advancement of Science (AAAS), 1993, 2011; Bybee, 1997; Kagan, 1992; National Association of Biology Teachers (NABT), 2010; National Research Council (NRC), 1996]. Without evolutionary theory, biology is reduced to an assemblage of tangential and loosely connected facts. Despite possessing a unifying theory, biology as a subject is still frequently viewed by students as being a disparate and nonsensical field requiring extensive levels of memorization of seemingly unrelated topics (Nomme, 2014). Given this perceived disconnect between topics, every aspect of biology becomes more difficult or even impossible to understand and is therefore avoided by many students (Nomme, 2014).

A major factor contributing to the dissociation of concepts in biology is the fact that the unifying element (evolutionary theory) is so widely rejected. Nearly a third of American adults firmly reject evolution (Miller et al., 2006), and less than a quarter accept evolution of humans (Lovely & Kondrick, 2008). Among educators, evolution is occasionally rejected and frequently ignored or marginalized as to evade what is perceived as avoidable conflict with both students and parents (Lerner, 2000; Farber, 2003; Olivera et al., 2011; Verhey, 2005; Goldston & Kyzer, 2009). This widespread rejection within the general populous comes despite near complete consensus among scientists (Pew Research Center, 2015; Alters & Alters, 2001). If the central organizing theory of the entire field of biology is rejected, then there is some question as to the utility of attempting its instruction at all. If what is taught isn't internalized, then it becomes

nothing more than trivia. Biology is generally considered a part of a general education at all levels, yet students that do not receive instruction about or that do not accept evolution are less likely to retain the information (Nehm & Schonfeld, 2007) or transfer their understanding to applications outside of the course itself (Nehm & Reilly, 2007; Catley & Novack, 2009; Fowler & Zeidler, 2016).

Instruction Does Not Mean Acceptance

Understanding that evolution is almost universally accepted by scientists, one might postulate that rejection of evolutionary theory is related to general ignorance of the subject matter. This might seem particularly plausible given that most students are unable to properly articulate what evolutionary theory posits (Robbins & Roy, 2007), and there is a correlation between knowledge of evolution and acceptance (Weisberg et al., 2018). As knowledge of evolution generally increases with instruction (Kim & Nehm, 2011; Moore et al., 2011) it has been frequently hypothesized that acceptance of evolution should be positively correlated with instruction and knowledge of evolution, especially natural selection (Anderson et al., 2002; Bishop & Anderson, 1990; Demastes et al., 1995; Lord & Marino, 1993; Nehm & Schonfeld, 2008; Sinatra et al., 2003). However, these studies have revealed no such correlation. For example, Sinatra et al. (2003) found that after instruction about photosynthesis, evolution of animals, and human evolution that students' acceptance of photosynthesis, the non-controversial control, went up significantly, but there was no such increase in acceptance for either animal nor human evolution following similar instruction on these topics. Though some studies have shown an increase in

acceptance with instruction (Weisberg et al., 2018; Robbins & Roy, 2007), particularly outside of the United States (Akyol et al., 2010; Kim & Nehm 2011; Ha et al., 2012), it more often seems to be an effective means of temporarily increasing knowledge of evolution, but not acceptance (Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley 1996; Sinatra et al. 2003, Asterhan and Schwarz 2007, Stover and Mabry 2007, Rutledge & Sadler 2011; Deniz & Donnely, 2011; Lawson & Worsnop, 1992; Crawford et al., 2005; Cavallo & McCall, 2008). Thus, the correlation between understanding and acceptance likely indicates that acceptance is a predictor of understanding and not the other way around (Smith & Siegel, 1994).

If biology is going to remain a meaningful part of a general education, then it stands to reason that we need to teach it in such a way that promotes retention of the material and the application thereof by the students to the real world. If students are going to accomplish these goals, then we need to teach it in such a way that they can accept what is being taught. As acceptance is not, generally, correlated with instruction it leads to the question, what can we do to make instruction about evolution truly effective? To answer this question, we engaged in a detailed look at the literature to see what ideas have been presented and tested that might, if implemented in classrooms, increase the efficacy of biology teaching by increasing acceptance of biological evolution.

The Correlates of Acceptance

Many factors such as per capita gross domestic product (Heddy & Nadelson, 2012), parents' education level (Deniz et al., 2008), conservative political orientations (Nadelson & Hardy, 2015), and feeling of certainty (Ha et al., 2012), have been shown to be correlated with acceptance of evolution. Some of the most frequently observed correlates are religiosity and basic science literacy (Heddy & Nadelson, 2012, Glaze et al., 2015), particularly with understanding of evolution and of the nature of science (Cofré et al., 2018; Dunk et al., 2017; Lombrozo et al., 2008; Trani, 2004; Glaze et al., 2015; Cavallo et al., 2011; Carter & Wiles, 2014; Weisberg et al., 2018). Generally, religiosity is found to have a negative correlation with acceptance of evolution in that the more religious an individual is, the less likely they are to accept evolution (Heddy & Nadelson, 2012; Glaze et al., 2015). Conversely, correct understanding of the nature of science and of evolutionary theory are positively correlated with acceptance (Lombrozo et al., 2008; Trani, 2004; Glaze et al., 201; Cavallo et al., 2011; Weisberg et al., 2018). As stated previously, knowledge of evolution is not always found to be correlated with acceptance. When knowledge and acceptance are correlated, it sometimes only makes a difference in students that were undecided on the subject before instruction (Wilson, 2005; Ingram &

Nelson, 2006). It could be that knowledge and understanding are not always synonymous because constructing such an understanding can be impeded by misconceptions both present in students and taught by instructors (Blackwell et al., 2003; Sinatra et al., 2008; Yates & Marek, 2014). Assuming a causative relationship between these correlates and acceptance, one could conceivably increase acceptance of evolution by doing any of the following: increasing students' understanding of the nature of science, increasing students' correct understanding of evolutionary theory particularly of "macroevolution", or the idea that the small-scale "micro" evolutionary steps can accumulate and lead to speciation (Nadelson & Southerland, 2010), or by decreasing students' religious conviction.

Reduce Religiosity

Considering the negative correlation between religiosity and acceptance of evolution, many teachers and popularizers of science have attempted to confront the apparent incompatibility of science and religion by attempting to discredit the religious beliefs of the students (Dawkins, 2016; Mahner & Bunge, 1996). While this may be effective for some, it is also likely that it simply reinforces the belief that science and religion are incompatible and therefore hinders acceptance in those who are unconvinced that they should abandon their religious beliefs. In addition, promoting an accurate understanding of students' religious doctrine and discussing ways in which science and religion can be reconciled can lead to higher levels of acceptance of evolution even among highly religious students (Brickhouse et al., 2000; Manwaring et al., 2015; Barnes et al., 2017). Winslow et al., (2011) found that among Christian students raised as creationists, acceptance was possible when students were presented with evidence, when they were encouraged to examine the literalness of the scriptural accounts of creation, when evolution was presented as something unrelated to their eternal salvation, and when their professor was viewed as a religious role model who accepted evolution. Holt et al., (2018) found that "The single factor linked with the reduction in both creationist reasoning and in students' perceived conflict between evolution and their worldview through a semester was the presence of a role model."

Along those lines, it is essential to differentiate between accepting and believing in evolution as belief and acceptance are not, necessarily, synonymous (Smith & Siegel, 2004). Evolution is not a belief system, but a rational explanation for a host of facts which, to date, cannot otherwise be explained. One therefore does not believe in evolution but accepts it as the most reasonable explanation we have given the facts. This understanding is likely associated with understanding of the nature of science and its limitations, and if understood could mitigate the belief

that accepting evolution threatens ones' eternal salvation (Winslow et al., 2011).

All of this would suggest that, for highly religious students, the best way to promote acceptance might not be to attack their beliefs, but to aid them in reconciling their beliefs with science and serving as a non-hostile role model. In the case that the instructor holds uninformed or antagonistic viewpoints towards religion this approach should only be implemented with great care (Brickhouse et al., 2000). Regardless, presenting science as an antithesis to religion may do more to promote rejection than acceptance. Whether it is effective or not to diminish the religious beliefs of students, Rice et al., (2015) found that, for university faculty, knowledge and acceptance of evolution were positively correlated, even in faculty with creationist viewpoints, suggesting that acceptance and knowledge can increase conjointly irrespective of the religious position of the learners. Attacking the students' religious convictions is likely not the best way to increase the likelihood of accepting evolution.

Reduce Misconceptions

Given the variation in the strength of students' religious beliefs as well as the compatibility of those beliefs with evolutionary theory, in many instances it may be counter-productive to engage those convictions directly or indirectly. Attempting to increase acceptance of evolution by confronting student religiosity may not always be an effective option for instructors. One of the principle issues related to religion and science is that religious students may be at an increased risk of possessing misconceptions that hinder proper understanding of science generally, especially evolution (Dagher & BouJaoude, 1997; Sinatra et al., 2003; Blackwell et al., 2003). To increase the likelihood of acceptance among religious students it may be effective to address those misconceptions in lieu of confronting the religion directly.

The importance of confronting misconceptions is not limited to religious students in any way, but such misconceptions permeate society irrespective of religiosity (Blackwell et al., 2003; Sinatra et al., 2008; Yates & Marek, 2014). In some cases, people may claim to reject evolution based on their religious convictions, but this may not be the actual motivation. Trani, (2004) found that many teachers claimed to reject evolution due to their religion, but upon further analysis it appeared to be more due to a lack of understanding of the actual theory of evolution, and a lack of understanding of the nature of science.

To confront the acceptance barrier of misconceptions one could confront those misconceptions directly in the classroom as a part of the curriculum. Misconceptions about evolution are numerous and include things such as those listed by Gregory, (2009). Wilson, (2005) designed an entire

course with the objective of increasing interest in, knowledge and acceptance of evolution. In the course the researchers focused the beginning of the course on the implications of evolution as many of the most common reasons for dismissing the theory come from incorrect assumptions regarding its implications. Although some have chosen to devote the whole of a course to confronting such misconceptions, all biology courses are likely to benefit from taking time to assess and address the misconceptions present in the students.

What may be better than correcting misconceptions would be to begin to teach evolution explicitly as early as possible to students so that they can develop accurate initial conceptions regarding evolution and the nature of science before they have the opportunity to construct inaccurate ones (Weiss & Dreesmann, 2014). Kelemen et al., (2014) found that children from 5 to 8 years of age can be taught basic natural selection using a picture-storybook and retain and apply that information even several months after instruction. Contrary to what many might think, correct understanding of evolution does not seem to be outside of the reasoning ability of even very young students.

Capability of Teachers

Among the major considerations which may prevent earlier implementation of evolution into curricula is the understanding of the teacher. Being that we are seeking to evade misconceptions among learners, it is important to consider that many teachers of younger students themselves possess these misconceptions (Blackwell et al., 2003; Yates & Marek, 2014). Elementary teachers, for example, may have a single semester or less of biology education before beginning teaching, a single course which may or may not have taught accurate principles of biological evolution. Teachers are often not sufficiently knowledgeable to correctly teach these concepts and may deliberately or inadvertently teach misconceptions explicitly in the classroom. Even among more highly trained biology-specific teachers, such misconceptions are prevalent. Many either teach these misconceptions, or use them, combined with concerns of parent outrage, as an excuse to avoid the topic altogether. Rutledge & Mitchell, (2002) found that 43% of surveyed teachers completely avoided, or only briefly mentioned evolution in Indiana biology classrooms. The principle reasons that the topic was avoided was that the teachers felt ill-equipped in terms of their personal understanding or rejected it themselves. Some teachers do not want to teach evolution, others are incapable (Wiles & Branch, 2008). Though beginning evolution education at an earlier age may increase the likelihood of acceptance, it is unlikely that our current workforce of teachers is adequately trained to do so.

If we are to have teachers that are more equipped to teach evolution in schools then we need a better way to teach not only our students, but our teachers (Weiss & Dreesmann, 2014; Blackwell et al., 2003). Rutledge & Warder, (2000) found that Indiana public high school biology teachers were ill-prepared by their academic qualifications to teach evolution, or the nature of science and that most college and university biology departments do not require evolution or nature of science coursework to obtain teacher certification in biology. Even when attempts are made to design courses to increase instructor knowledge of evolution these courses are frequently ineffective at changing the way that instructors teach. For example, a course taught at the graduate-level to instructors designed to increase instructor knowledge and reduce misconceptions was effective at increasing knowledge and reducing misconceptions, but did not reduce the desire of instructors to teach anti-evolutionary ideas (Nehm & Schonfeld, 2007) suggesting that it did not have an impact on instructor acceptance.

For students and educators that have received quality instruction, but especially for those whose early-life evolution education has left them either uninformed or misinformed about evolution, the question then becomes how do we teach evolution so that they will be most able to understand and accept it?

Constructivism

Alters & Nelson, (2002) suggested teaching using constructivism as a means of increasing the efficacy of evolution teaching. Constructivism, when applied not only as a theory of learning but as a theory of education, should promote conceptual change in learners because it, unlike many other educational theories such as behaviorism, is not capable of ignoring the misconceptions and past experiences of the students. With behaviorism, instructors may elicit desired responses from learners with sustained reinforcement of those behavioral responses. However, the knowledge that they are to attain is not owned by the learner, but is predetermined by the instructor. Understanding is only measured by the learner behaving in the manner desired by the instructor (such as repeating a word or phrase) in response to specific stimuli (such as a test question), which are again determined by the instructor (Scheurman, 1998). Behaviorism treats learners as though they were a blank slate and does not account for the effect that their preconceived notions may have on their ability to learn new material (Ertmer & Newby, 1993). Cognitivism accepts that learners may have preconceived notions that may interfere with their ability to obtain knowledge, but it still views knowledge as something created outside of the learner and therefore something inflicted upon the learner and not constructed thereby (Ertmer & Newby, 1993). Constructivism is arguably a subset of cognitivism that assumes that knowledge cannot be transferred intact

from one individual to another, but rather that all people construct within themselves a logical set of explanations for the experiences that they have had (Jonassen, 1999). When we ignore the past experiences of a learner, we are unable to predict how they will incorporate the new information being presented into their existing schemas. A constructivist classroom will raise questions and problems that require students to do things based on their prior beliefs, but that have results or answers which may not fit into their existing schemas requiring students to reexamine their existing schemas to see if they remain credible, or if they need to be replaced (Lawson, 1994). In addition to confronting incorrect schemas that might otherwise go undetected, such experience may increase overall reasoning abilities, which, as suggested by Lawson & Wesner, (1990), should decrease nonscientific beliefs in students. These reasons should, at least hypothetically, make constructivist teaching more effective in terms of promoting acceptance of evolution.

Active Learning

Freeman et al., (2014) in a meta-analysis of 225 studies found that the use of active learning of any kind increased exam scores an average of 6% and that failure rates in STEM courses were 55% higher in non-active courses than in active courses. Active learning was also suggested as a means of increasing knowledge and acceptance of evolution specifically by Alters and Nelson, (2002) because learning tends to increase in active learning classrooms. Where learning increases, instructors have a greater chance of increasing student understanding of the two key knowledge correlates with evolution acceptance: the nature of science and of evolution. Nehm & Reilly, (2007), for example, found that classes taught using active learning achieved higher scores on key concepts of natural selection and had fewer misconceptions than classes taught traditionally. Active learning environments may too provide a greater opportunity for instructors to gain insight into the thoughts and misconceptions of their students and thus more able to address them deliberately in the classroom.

Journals

Reflective journals are already widely used in other fields of education such as nursing (Blake, 2005; Raterink, 2016; Miller, 2017), counselling (Chabon & Lee-Wilkerson, 2006; Hubbs & Brand, 2005), and statistics (Thropp, 2017). These journals proved an active-learning component to the course allowing the students to reflect on the material (Blake, 2005; Thropp, 2017), as well as giving instructors critical feedback into the understanding and application of the material in their students (Chabon & Lee-Wilkerson, 2006). In Biology classrooms, completing journaling assignments has been correlated with an increase in understanding and acceptance of biological evolution

(Scharmann & Butler, 2015). While the lack of a control in this study prevents us from knowing if journaling caused any portion of the increase in acceptance that the researchers observed, as with other fields, the journals helped researchers gain a clearer view into students' thoughts. Combined with the use of active learning in the classroom, they saw an increase in acceptance of evolution over the course of the semester. Journals may, in and of themselves, increase acceptance, but at the very least journals can inform instructors about the major misconceptions and understanding of their classes so that instructors can modify their curricula accordingly.

Make Evolution Relevant

To most biologists the importance of evolutionary theory is obvious as it not only makes sense of the field, but gives us the ability to understand and predict many real-world, relevant phenomena such as the spread of disease, pest management, and the potential impacts of climactic change. Many students, nonetheless, never see the practicality of the theory. Learning is often impeded because students do not see the relevance of the subject to their lives (Heddy & Sinatra, 2013). One of the great benefits of active learning is that it increases the attentiveness of the students (Prince, 2004), but if the material is trivial and irrelevant then such benefits may be lost (Heddy & Sinatra, 2013). Infanti & Wiles, (2014) found that exposing students to "Evo in the News" (news articles involving evolution) was correlated with increases in student attitudes regarding evolution and its relevance. Thus, we may benefit from not only explaining the historical importance of evolution but focusing on how evolution impacts modern life for our students. Stover et al., (2013) found that acceptance of evolution and other controversial topics in science increased when placed in a context of public health. As is often the case, science is perceived as most relevant when it is directly related to human health and survival. This would include the evolution of diseases, drug resistance, herb and pesticide resistance, communicability of diseases from other organisms, selective breeding and others. There are likely countless examples of ways that evolution impacts modern life, and the more examples we can bring to the students the more likely they are to listen to the content being shared.

Social Identity Theory

Social identity theory is a theory in social psychology that explains much about intergroup behavior based on their perceived membership to a relevant social group (Turner & Oakes, 1986; Tajfel et al., 1979; Tajfel & Turner, 1986). This theory led to the creation of self-categorization theory that describes the conditions under which an individual will identify assemblages of individuals (potentially including themselves) as being a group, and the

consequences of identifying people as a group (Haslam, S. A., 1997). Based on these theories, social identities are cognitively signified as group stereotypes that both describe and assign beliefs, attitudes and behaviors that minimize differences with members of one's perceived group and maximize differences with members of other groups whether those groups were formed randomly or non-randomly (Tajfel, 2010). As a result, people tend to be unreasonably critical of ideas that come from individuals outside of their perceived group, and unreasonably accepting of ideas that come from individuals within their perceived group (Tajfel, 2010). While research has not focused on the impact of social identity theory and in-group formation on evolution acceptance specifically, it would explain why acceptance rates vary based on factors such as political party and religious affiliation (Nadelson & Hardy, 2015). It stands to reason that students' perception of their instructor as being either part of their in-group or not part of their in-group could dramatically influence the probability of evolution acceptance among their students. This could potentially be addressed by taking steps to approximate the stereotypes of the students' in-group, or at least not deliberately portray oneself as a member of an out-group (Holt et al., 2018) and also by building a strong in-group culture in the classroom and never to isolate members of the class as being members of some other group.

Conclusions and Future Directions

While our understanding of the importance of accepting evolution and how to increase that acceptance is increasing, we still have much to accomplish. In many cases the implementation of this knowledge is inhibited by the fact that teachers are unable or unmotivated to make the changes necessary to improve the quality of biology education as to increase student acceptance of the fundamental theory of evolution. Despite the obstacles, there is great reason for optimism. A greater focus on student understanding of the nature of science and evolutionary theory promises to increase student acceptance particularly as these topics are presented in an active, constructivist, and relevant way. Gone are the days when we, as scientists, felt the need to engage in the battle of science versus religion to inform our students. We do not need to tear down as much as we need to confront misconceptions and build, as early as possible, correct ideas about the mechanisms and implications of evolution.

Many great ideas have been postulated regarding teaching strategies that are likely to increase acceptance. As we focus on studies that experimentally test these hypotheses, we are likely to have greater and greater clarity as to the most effective ways to present science and biology to modern students. As we understand how to address

controversial topics such as evolution we are likely to gain insight into how we might better inform the public about a host of other relevant and important topics that are similarly perceived as being controversial (e.g., reproductive technology, climate change). We have long been fighting this battle, but we are constantly learning which battles really should be fought.

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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, nor should they use any hidden from view editing tools. All weights and measures must be given in the SI (metric) system.

In- text citations should be done in the following manner:

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).

- C. 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.

- D. Example citations are below.

(1) Articles-

(a) Single author:

DeBuhr, L. E. (2012). Using Lemna to Study Geometric Population Growth. *The American Biology Teacher*. <https://doi.org/10.2307/4449274>

(b) 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. [https://doi.org/10.1016/0012-1606\(68\)90048-1](https://doi.org/10.1016/0012-1606(68)90048-1)

(c) Mutli-authored more than seven authors

List the first six authors than an ellipsis followed by the last author.

(2) Books-

Bossel, H. (1994). *Modeling and Simulation* (1st ed.). New York, NY: A K Peters/CRC Press. <https://doi.org/10.1201/9781315275574>

(3) Book chapters-

Glase, J. C., & Zimmerman, M. (1993). Population ecology: Experiments with Protistans. In J. M. Beiswenger (Ed.), *Experiments to Teach Ecology* (pp. 39–82). Washington, DC: Ecological Society of America. Retrieved from <https://tiee.esa.org/vol/expv1/protist/protist.pdf>

(4) Web sites-

McKelvey, S. (1995). Malthusian growth model. Retrieved November 25, 2005, from <https://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html>

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 accompanied by a descriptive legend using the following format:

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** ($\geq 300\text{dpi}$) 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. No figures put together using a cut and past method will be accepted. All figures should be accompanied by a descriptive legend using the following format:

Fig. 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.
- C. Make sure that recommended changes have been made or a clear explanation as to why they were not.
- D. Figures and legends sent separately, but placement in manuscript should be clearly delimited.

VIII. Editorial Policy and Copyright

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