Exploring New Approaches to the Problem of Plant Awareness Disparity in Undergraduate Students

Kathryn McKenna Parsley

Follow this and additional works at: https://digitalcommons.memphis.edu/etd

Recommended Citation


This Dissertation is brought to you for free and open access by University of Memphis Digital Commons. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of University of Memphis Digital Commons. For more information, please contact khggerty@memphis.edu.
EXPLORING NEW APPROACHES TO THE PROBLEM OF PLANT AWARENESS DISPARITY IN UNDERGRADUATE STUDENTS

by

Kathryn M. Parsley

A Dissertation
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy

Major: Biology

The University of Memphis
May 2021
DEDICATION

To the plants,
Who have been my silent and watchful friends ever since I can remember.

To Elisabeth Schussler and James Wandersee
Who gave me the language to describe my frustrations with my fellow students during our botany class (and then encouraged me to go and change it).
ACKNOWLEDGMENTS

Thank you to my major advisor, Dr. Jaime Sabel, for more than I can begin to say. Thank you for supporting me, for challenging me, for allowing me academic freedom in my projects, and for encouraging me to chase even my wildest of dreams. Thank you for supporting me and looking out for me. Thank you for always striving to be better and giving me such an excellent example of how to do that for myself. Thank you for reminding me of how far I’ve come and to celebrate the achievements I have earned, even (and perhaps especially when) I am discouraged by what I have not yet achieved. Thank you for being my mentor, my collaborator, and my friend.

Thank you also to Brian Sabel for helping me fix both of my cars and for making such excellent drinks and music.

Thank you to my committee, Dr. Elisabeth Schussler, Dr. Judy Cole, Dr. Jennifer Mandel, Dr. Bernie Daigle, and Dr. Katie Wade-Jaines for your unwavering support and encouragement throughout my tenure at the University of Memphis. Thank you for pushing me, challenging me, and believing in me. Thank you especially to Dr. Elisabeth Schussler, who has helped me make more connections than I ever imagined possible, and for telling people I am the, “new plant blindness queen.” Thank you to Dr. Bernie Daigle who not only taught me how to code in R (an impressive feat in and of itself) but also willingly stepped in as a committee member in the final stages of my dissertation.

Thank you to all of my teachers and mentors but thank you especially to Dr. Lila Peal who was the first person to ever see me as a scientist and to convince me that it was possible to become one. Thank you also to Dr. Michael Dunn, Dr. Gary Upchurch, and
Dr. Paula Williamson for shaping my idea of what it means to be a scientist, and especially, a botanist.

Thank you to the University of Memphis Center for Biodiversity Research for awarding me two grants that allowed me to collect data for two of the four studies within this dissertation.

Thank you to my fellow graduate student, Kendra Wright, and all of the undergraduate students who worked with me on the various projects within and related to my dissertation. Thank you to my friends who have helped to keep me sane throughout the entire process of writing this dissertation and encouraged me to keep going: Dr. Malle Carrasco-Harris, Dr. Elyan Shor, (soon to be Dr.) Sara Salisbury, Aaron Bevington, and Jacob Jardel.

Finally, thank you to my uncle, Kyle Giblet, for encouraging me to keep going, for helping me find the warrior in me, for helping me learn how to be autistic in academia, and for being the one person in my life who just gets it.
PREFACE

This dissertation contains 6 chapters, 2 of which are formatted according to the journals to which they have been submitted. The introductory Chapter 1 and concluding Chapter 6 are formatted according to APA 7th edition.

Chapter 2 has been submitted to a journal that requires APA 7th edition format as:
Parsley, K.M. Daigle, B.J., & Sabel, J.L. Development and Validation of the Plant Awareness Disparity Index to Assess Undergraduate Levels of Plant Awareness Disparity.

Chapter 3 will be submitted to a journal that requires APA 7th edition as: Parsley, K.M., Sabel, J.L., Zangori, L., & Koontz, J. Pollution without People: Evaluating Plant Awareness Disparity and Student Perceptions of the Role of Humans in Plant-related Socioscientific Issues.

Chapter 4 and 5 have not yet been submitted and follow APA 7th edition format.
ABSTRACT

Parsley, Kathryn M. Ph.D. The University of Memphis. May 2021. Exploring new approaches to the problem of plant awareness disparity in undergraduate students. Major professor: Dr. Jaime Sabel

Plant awareness disparity (PAD, formerly plant blindness) is the tendency not to notice plants in one’s environment. PAD is made of four components: attention (not noticing plants), attitude (not liking plants), knowledge (not understanding why plants are important), and relative interest (being less interested in plants than in animals). This can lead to a host of misconceptions regarding plants, such as plants do not evolve, or that humans do not need plants. Previously, many interventions have been suggested to address PAD in undergraduate students. However, the success of these interventions cannot be fully determined without a way to measure PAD. Therefore, I developed and validated an instrument to measure PAD in undergraduate students. Additionally, previous strategies to address PAD have assumed that once students know more about plants, they will automatically notice plants more. Because of the complex nature of PAD and its four components, this assumption is likely incomplete as it does not address student attitudes toward or interest in plants. As such, I also developed and characterized a conceptual framework known as functional botanical literacy (FBL). FBL is defined as the ability to make sound scientifically-informed decisions regarding botanical socioscientific issues (SSIs) such as genetically modified organisms (GMOs), plant conservation, deforestation, and biofuels. This conceptual framework is designed to both engage student interest in plants and improve attitudes toward plants through the use of SSIs that are more likely to help students see why plants are relevant to their everyday lives. Major findings include how undergraduate botany students think of humans in the
context of the environment and FBL, how course and assignment structure differently affect FBL, and that even one decision-making intervention can greatly improve non-majors introductory biology students’ level of FBL and the skills associated with it.

Implications include how to more holistically address PAD and improve not only student knowledge of plants, but also their science literacy skills and their appreciation for how important plants are to the biosphere and human affairs.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>xii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xiv</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>Study Rationale</td>
<td>6</td>
</tr>
<tr>
<td>Research Questions and Overview of Studies</td>
<td>10</td>
</tr>
<tr>
<td>References</td>
<td>12</td>
</tr>
<tr>
<td>Chapter 2: Initial development and validation of the plant awareness disparity index</td>
<td>17</td>
</tr>
<tr>
<td>Introduction</td>
<td>17</td>
</tr>
<tr>
<td>Methods</td>
<td>21</td>
</tr>
<tr>
<td>Pilot Study Results</td>
<td>25</td>
</tr>
<tr>
<td>Exploratory Factor Analysis: Round One</td>
<td>39</td>
</tr>
<tr>
<td>Exploratory Factor Analysis: Round Two</td>
<td>42</td>
</tr>
<tr>
<td>Discussion</td>
<td>51</td>
</tr>
<tr>
<td>Limitations</td>
<td>54</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>55</td>
</tr>
<tr>
<td>Appendices</td>
<td>56</td>
</tr>
<tr>
<td>References</td>
<td>62</td>
</tr>
<tr>
<td>Chapter 3: Pollution without people: Evaluating plant awareness disparity and student perceptions of the role of humans in plant-related socioscientific issues</td>
<td>66</td>
</tr>
<tr>
<td>Introduction</td>
<td>66</td>
</tr>
<tr>
<td>Background Literature</td>
<td>69</td>
</tr>
<tr>
<td>Conceptual Framework</td>
<td>74</td>
</tr>
<tr>
<td>Methods</td>
<td>79</td>
</tr>
<tr>
<td>Results</td>
<td>89</td>
</tr>
</tbody>
</table>
Chapter 4: Characterizing functional botanical literacy: Exploring a conceptual framework for addressing plant awareness disparity ........................................... 137

Introduction ........................................................................................................ 137

Conceptual Framework ..................................................................................... 140

Methods ............................................................................................................. 145

Results ............................................................................................................... 151

Discussion ......................................................................................................... 175

Acknowledgments .............................................................................................. 185

Appendices ......................................................................................................... 181

References .......................................................................................................... 211

Chapter 5: How decision making about a botanical socio-scientific issue changes over the course of a decision-making intervention ................................................ 216

Introduction ........................................................................................................ 216

Conceptual Framework ..................................................................................... 218

Methods ............................................................................................................. 223

Results ............................................................................................................... 228

Discussion ......................................................................................................... 244

Limitations ......................................................................................................... 249

Acknowledgments .............................................................................................. 250

Appendices ......................................................................................................... 251

References .......................................................................................................... 261

Chapter 6: Discussion ......................................................................................... 266
Overall Remarks .................................................................................................................................................. 266
Chapter Summaries ......................................................................................................................................... 273
Conclusions ...................................................................................................................................................... 285
Future Directions ........................................................................................................................................... 290
Concluding Remarks ...................................................................................................................................... 291
References ....................................................................................................................................................... 292
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2: Initial development and validation of the plant awareness disparity index</td>
<td></td>
</tr>
<tr>
<td>Table 1. Pre/post PAD-I scores for trimester 1</td>
<td>26</td>
</tr>
<tr>
<td>Table 2. Pre/post PAD-I scores for trimester 2</td>
<td>27</td>
</tr>
<tr>
<td>Table 3. A comparison of the four models tested during EFA study two using goodness-of-fit indices</td>
<td>44</td>
</tr>
<tr>
<td>Table 4. Items and factor loading scores of the final version of the PAD-I</td>
<td>46</td>
</tr>
<tr>
<td>Chapter 3: Pollution without people: Evaluating plant awareness disparity and student perceptions of the role of humans in plant-related socioscientific issues</td>
<td></td>
</tr>
<tr>
<td>Table 1. Student demographic information</td>
<td>81</td>
</tr>
<tr>
<td>Table 2. Frequencies of plant awareness disparity components</td>
<td>91</td>
</tr>
<tr>
<td>Table 3. Results of PAD-I and semester one pre-test causal map criteria correlation analysis</td>
<td>98</td>
</tr>
<tr>
<td>Table 4. Frequencies of human links codes found in interviews</td>
<td>102</td>
</tr>
<tr>
<td>Chapter 4: Characterizing functional botanical literacy: Exploring a conceptual framework for studying plant awareness disparity</td>
<td></td>
</tr>
<tr>
<td>Table 1. Coding and Evaluation Approach to Determine if Students Demonstrate FBL</td>
<td>151</td>
</tr>
<tr>
<td>Table 2. Codes and frequencies for UNL module assessment decisions with examples</td>
<td>153</td>
</tr>
<tr>
<td>Table 3. Codes and frequencies for UNL module assessment scientific information with examples</td>
<td>156</td>
</tr>
<tr>
<td>Table 4. Codes and frequencies for UofM essay decisions with examples</td>
<td>160</td>
</tr>
<tr>
<td>Table 5. Codes and frequencies for UofM essay scientific information with examples</td>
<td>164</td>
</tr>
<tr>
<td>Table 6. Codes and frequencies for UNL and UofM interview decisions with examples</td>
<td>168</td>
</tr>
<tr>
<td>Table 7. Codes and frequencies for UNL and UofM interview scientific information with examples</td>
<td>172</td>
</tr>
<tr>
<td>Chapter 5: How decision making about a botanical socioscientific issue changes over the course of a decision-making intervention</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. Class decision frequencies across all three assignments .................................. 232
Table 2. Most popular decisions across all assignments with examples ....................... 234
Table 3. Class rationale frequencies across all three assignments ............................. 240
Table 4. Most popular rationales across all assignments with examples ...................... 242

Chapter 6: Discussion

Table 1. Chapter summaries ............................................................................................ 269
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2: Initial development and validation of the plant awareness disparity index</td>
<td></td>
</tr>
<tr>
<td>Figure 1. Alignment of preliminary hypothesized factors from factor analysis with previously hypothesized factors based on the four components of PAD</td>
<td>41</td>
</tr>
<tr>
<td>Figure 2. Alignment of EFA-reinforced six-factor model with original four components of PAD</td>
<td>45</td>
</tr>
<tr>
<td>Chapter 3: Pollution without people: Evaluating plant awareness disparity and student perceptions of the role of humans in plant-related socioscientific issues</td>
<td></td>
</tr>
<tr>
<td>Figure 1. Elements of Functional Botanical Literacy</td>
<td>74</td>
</tr>
<tr>
<td>Figure 2. Picture of an environment students were asked to consider for development of their causal maps</td>
<td>84</td>
</tr>
<tr>
<td>Figure 3. Number of causal maps assigned to each human links score category</td>
<td>88</td>
</tr>
<tr>
<td>Figure 4. Examples of each level of causal map scoring</td>
<td>101</td>
</tr>
<tr>
<td>Chapter 4: Characterizing functional botanical literacy: Exploring a conceptual framework for studying plant awareness disparity</td>
<td></td>
</tr>
<tr>
<td>Figure 1. Elements of Functional Botanical Literacy</td>
<td>140</td>
</tr>
<tr>
<td>Chapter 5: How decision making about a botanical socioscientific issue changes over the course of a decision-making intervention</td>
<td></td>
</tr>
<tr>
<td>Figure 1. Elements of Functional Botanical Literacy</td>
<td>218</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

Background

Defining Plant Awareness Disparity (PAD)

Since 1919, when general biology courses were first being developed, professors have noticed that the words “biology” and “zoology” seemed to be synonymous in these courses (Nichols, 1919). Plant awareness disparity (PAD, formerly plant blindness) is known as the tendency not to notice or appreciate plants in one’s own environment which can lead to a host of problems and misconceptions among students and teachers (Parsley, 2020; Wandersee & Schussler, 2001). Some of these problems include lack of support for conservation of plants (Balding & Williams, 2016), prejudice against plants and teaching them among biology teachers (Hershey, 1993), zoochauvinism (or the idea that animals have more value than plants), lack of representation of plants in the media, and even plant neglect in biology textbooks (Hershey, 2002; Brownlee et al., accepted). This prejudice can be demonstrated in the way teachers choose examples of universal biological concepts such as evolution. A teacher with PAD is less likely to choose a plant-related example of evolution and instead will often opt for an animal-related example of this concept (Hershey, 1993; Hershey, 2002).

PAD is proposed to have four components: attention, attitude, knowledge, and relative interest, according to Dr. Elisabeth Schussler (E. Schussler, personal communication, May 13, 2019; Parsley, 2020). Attention is tied to the classical definition of PAD and refers to how much students notice plants in general. Attitude is how students feel about plants, particularly in situations where they are asked to learn about them.
Knowledge refers to knowledge about the importance of plants. Relative interest indicates how interesting students find plants compared to other organisms, namely animals.

**Characterizing PAD**

Exploratory studies have examined causes for, and patterns surrounding, PAD to better characterize the phenomenon. For example, Schussler and Olzak (2008) noted that university students recall more animal names than plant ones, even if they are equally nameable examples. They also discovered that attending a botany class had no effect on college students’ differential ability to recall plants versus animals, and that women in general were more likely to recall plant names than men in both a psychology and botany course. The difference in ability to recall plant images across genders is thought to be due to a socialization of flowers as more, “feminine,” in Western society (Schussler & Olzak, 2008). Notably, women in the study recalled bouquet flowers such as carnations, daisies, and roses the most. Balas and Momsen (2014) noted differences in attentional blink for university students when considering plants and animals, meaning that students were better able to detect animals than plants when shown images of each in rapid succession. This phenomenon indicates that the attentional part of PAD is caused by a visual perception bias in which attention is captured more strongly and for a longer period of time by animals than by plants (Balas & Momsen, 2014). There is even evidence that students do not perceive plants as being alive due, in part, to plants’ lack of immediately observable motion (Yorek, Sahin, & Aydin, 2009).

Lindemann-Mathies (2005) demonstrated that children 8-16 years old tended to have more appreciation for showy and decorative plant species, as well as animals that
were pets or exotic, and they only appreciated more wild plants and animals after an educational intervention. Interestingly, this points not only to lack of attention to plants, but lack of attention to anything that does not qualify as being a member of charismatic megafauna. Charismatic megafauna are species that receive more attention from the media and are used as examples of why we should protect and conserve the environment (Barney et al., 2005). Patrick and Tunnicliffe (2011) demonstrated that children of the ages four, six, eight, and ten are in touch with their environment to varying extents, and that children who have rich experiences outdoors tend to have more knowledge about both plants and animals. Nyberg et al. (2019) noted that elementary school student teachers notice plants in environments where plants are in the foreground (such as botanical gardens), much more than in environments where animals are the focus (such as a science center).

**Interventions for PAD**

Many interventions have been proposed to address PAD in K-12 classrooms, as well as university learning environments (e.g., Hershey, 2002; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman 2006). Wandersee, Clary, and Guzman (2006) probed community college students’ botanical sense of place to help them see and understand how plants are important to not only the students, but also humans in general. They found that by doing this, students returned to their youthful wonder and enjoyment of certain plants, their motivation to learn plant biology increased, and their past positive feelings towards plants were reactivated which then sparked botanical awareness and appreciation. Students even spontaneously shared plant-related personal stories which in turn bonded the entire class into a plant-centered learning community (Wandersee, Clary,
& Guzman, 2006). Frisch et al., (2010) used this approach to help educate science teachers about why teaching plants in elementary school is important as well.

One way to help reduce PAD among college students is through a research-centered botanical curriculum (Ward, Clarke, & Horton, 2014), though there are several constraints surrounding the idea such as time, availability of research supplies, and flexibility of college curricula. Krosnick et al., (2018) utilized a Pet Plant Project where university students were asked to grow an unknown plant from seed, monitor its progress, and relate lecture concepts to its development. They found that students noticed plants more, wanted to plant their own plants, and made connections with their plant that supported the content they learned in lecture.

A proposed way to alleviate PAD in K-12 students is through an outdoor education program, where students (ages 10 and 11) have hands-on opportunities to interact with the plants (Fančovičová & Prokop, 2011). Wyner and Doherty (2019) demonstrated that local trees in an urban environment can be used to decrease urban middle school students’ levels of PAD, despite a lack of large outdoor spaces present in these urban environments.

**Other Strategies for Reducing PAD**

Some authors have chosen to take a more generalist approach and suggest interventions and solutions in a wide variety of contexts. For example, Hoekstra (2000) noted that in order to help combat PAD, botanists need to partner with the media and get better at presenting information in a relatable and entertaining way. Introductory biology textbooks need to improve their representation of plants in images at both the elementary
and university levels (Brownlee et al., accepted; Link-Pérez et al., 2010). Hershey (2002) had several ideas for combating PAD: a college course for preservice teachers, an online botanical glossary, a botanical seal of approval on biology textbooks from botanists, and even a bibliography of accurate botanical and biological teaching materials. Unfortunately, none of these approaches have been formally tested.

Wandersee and Schussler (2001) noted that having a knowledgeable and friendly plant mentor lowers PAD in students. Having experiences with a plant mentor also results in increased attention to, interest in, and scientific understanding of plants at a later point in life for many people. It seems that personal experiences with plants are of utmost importance when trying to evaluate and reduce PAD. Wandersee and Schussler took an activist approach in their 1999 paper, in which they announced that they were launching a campaign to “prevent plant blindness,” as it was then called, which was followed up with special posters to hang in classrooms and even a children’s book about a plant. To follow up with this idea, they even created an award called the Giverny Award for children’s books that accurately teach at least one scientific principle, and preference is given to books that teach about botany and plant biology.

Many different attempts have been made to address PAD, but it is difficult to tell the extent to which these attempts have been effective due to a lack of an assessment to measure PAD. Additionally, the majority of these interventions have been focused primarily on student attention, which is the hardest component of PAD to overcome as it is a visual cognition problem (Balas & Momsen, 2014; Wandersee & Schussler, 1999). Now that we have a better view of the different components that are encompassed within the over-arching term of PAD, it is time for a more thorough characterization of the
phenomenon and the development of a holistic approach to address this problem (Parsley, 2020). My work contributes a new measurement tool for PAD (Chapter 2), as well as a new conceptual framework and associated interventions that will improve students’ scientific and botanical literacy skills while potentially reducing PAD (Chapters 3-5).

**Study Rationale**

**Evaluation of Efforts to Reduce PAD**

While all of these strategies to target student attention toward plants have been shown in some ways to help alleviate PAD, it is impossible to know for sure if they fully address all aspects of PAD (or simply an idea related to PAD) without a way to reliably measure PAD in university students. For example, the Plant Attitudes Questionnaire was developed to measure attitudes toward plants in Slovakian students, ages 10-15 years old (Fančovičová & Prokop, 2010). However, this questionnaire does not measure the entirety of PAD and is limited by the specific demographic background used to validate the instrument. It is for this reason that my work contributes a new way to measure PAD in undergraduate biology students. The Plant Awareness Disparity Index (PAD-I) is a valid and reliable self-report measure for students that includes all four components of PAD (Chapter 2). The PAD-I will allow for a more holistic view of how and to what extent students demonstrate PAD and can be used in any biology course at the university level. Having this tool will allow university instructors the ability to determine if their intervention is truly effective at reducing PAD and all of its components.
SSIs to Capture Student Interest

Strgar (2007) suggested that teacher involvement including specialist knowledge, enthusiasm, and interest of the instructor greatly influences student interest in plants during fifth grade, eighth grade, and at the university level. Similarly, Wandersee (1986) stated that motivation and interest are as much an effect of learning as a cause, and that seventh, eighth, and ninth grade teachers should capitalize on, but not be limited by, their students’ interests. Students ranging in ages from ten to 19 tend to be more interested in stimulant herbal drugs and medicinal plants, which should therefore be used to teach botanical concepts more often in order to capture and hold student attention (Pany, 2014; Pany et al., 2019).

While studies that bring student interest to the forefront of PAD are noteworthy, none of them utilize socioscientific issues to accomplish this, despite calls to do so (Amprazis & Papadopoulou, 2018; Krishnan et al., 2019). Socioscientific issues (SSIs) are controversial scientific topics that are made up of a scientific and a societal component (Zeidler & Nichols, 2009). SSIs are meant to be personally meaningful and engaging to students while requiring evidence-based reasoning. Using SSIs for science learning adds context to school science and provides a natural opportunity to engage in causal reasoning, because students are able to use their science understandings to grapple with real issues that intersect with their lives and connect to their communities (Sadler, 2004). The ability to understand and navigate SSIs has been posited as a key component to scientific literacy (Sadler & Zeidler, 2003). Additionally, SSI teaching has been shown to enhance citizenry and student participation in social contexts beyond the classroom (Sadler et al., 2007).
Recently, Krishnan et al. (2019) demonstrated ways in which universities can partner with botanical gardens and other informal science institutions to bring food and agricultural plants to the public’s attention and called for further efforts in this arena. Amprazis and Papadopoulou (2018) called for better coverage of plants in primary school curricula to highlight their importance to human welfare and biodiversity. Both of these examples demonstrate how a plant-related socioscientific issue (such as food plants or the biodiversity crisis) can be used to bring in the natural interest of students while also clarifying the reasons that plants are relevant to students’ everyday lives.

In Chapter 3, I developed and explored aspects of a new conceptual framework known as functional botanical literacy (FBL) to help students make connections between plants and SSIs. I also used causal maps to determine whether the students were able to make these connections on their own, and if exposure to an active learning botanical curriculum improved these abilities. Chapter 3 was a highly exploratory study, and as such, did not prescribe a specific botanical SSI for students to consider. Instead, I opted to show students an image that included components which could easily be traced to a botanical SSI (for example, a factory releasing greenhouse gases into the atmosphere can be traced to climate change and how plants can improve climate change by acting as carbon sinks). This allowed me to see students’ natural ideas regarding plants, and to determine if they were already making these connections, which was an important first step to further understanding how FBL develops in undergraduate biology students.

One example of a specific botanical SSI that could be used to engage students in real world examples of how plants affect their everyday lives is plant conservation. Balding and Williams (2016) noted that intentionally anthropomorphizing and
empathizing with plants can lead to less PAD and even more support for plant conservation. Botanical SSIs such as plant conservation, genetically modified organisms (GMOs), climate change, and biofuels are all topics that could be used to enhance student interest in plants and help reduce PAD.

Rather than relying on plant conservation, my work utilizes biofuels as the prescribed botanical SSI for students to consider in studies three and four. Chapter 4 contributes a new approach to capturing student interest by characterizing FBL fully and comparing FBL levels between a scientific literacy course for mixed majors and a general biology course for nonmajors. This comparison will allow instructors to see what FBL looks like in two very different contexts. Additionally, this study provides a tool for instructors to use to evaluate their own course assignments for FBL. With this information, they will know what hallmarks to look for and how to identify FBL in their own students.

This approach of prioritizing student interest as well as knowledge is notable in that it does not assume that students who know more about plants will exhibit less PAD (as many previous studies have assumed). However, the approach that incorporates student interest is an important one, as the attention component is very difficult to overcome without addressing the other three components of PAD. Additionally, my research indicates that while knowledge and attention may improve, traditional botany education alone is not enough to improve student attitudes and interest in plants (Chapter 2; Parsley et al., in review). These latter components must be targeted directly via the use of a topic that will naturally interest students in plants, such as botanical SSIs (Chapter 3).
In chapter 5 I also explore what types of variables play into student decision-making, specifically when it comes to course context and assignment structure. When attempting a new approach to a problem as complex as PAD, it is worthwhile to consider what outside variables might affect that approach. I was able to compare FBL in two very different courses (a science literacy course for mixed majors and a general biology course for nonmajors) which gave me the advantage of being able to consider outside variables that should be considered when introducing a new SSI-based intervention in these very different contexts. Armed with this information, instructors will be able to make informed decisions about how best to structure their assignment (and perhaps their overall course) to better improve students’ FBL levels.

**Research Questions and Overview of Studies**

I conducted four studies to address the current gaps in knowledge surrounding how best to characterize and approach PAD in undergraduate biology students. Each of these studies utilized a slightly different approach and contributes a new tool to the literature that instructors will be able to use to more effectively combat PAD in their classroom. In each chapter, undergraduate biology students were given a tool or intervention to either determine their level of PAD or help them make connections between plants and SSIs.

In chapter 2 I developed and validated a new instrument to measure PAD in undergraduate biology students known as the Plant Awareness Disparity Index (PAD-I). In chapter 3 I developed a new conceptual framework known as functional botanical literacy (FBL) which is designed to both capture student interest in plants and improve
their scientific and botanical literacy. I explored parts of this framework with the help of a causal map tool to determine if students naturally made connections between plants and SSIs. In chapter 4, I fully characterized FBL as a framework and provided instructors with a way to evaluate their students’ work to determine the extent to which they demonstrate FBL. In chapter 5, I explored the effects of course context and assignment structure on students’ ability to develop FBL with the help of a targeted intervention. Each chapter has a separate set of research questions and is presented as a stand-alone paper and a part of the overall dissertation. Finally, chapter 6 provides a summary and discussion of all the studies, their findings, and their contributions to the literature.

While each chapter uses its own set of research questions, the following questions guided the overall dissertation:

1. In what ways can PAD be better characterized?
2. How can PAD be addressed from a holistic point of view, rather than focusing solely on student attention to plants?
3. What tools or approaches can address PAD from this new, holistic perspective?
4. What effect does time have on the efficacy of these tools?
References


Hershey, D. R. (2002). Plant blindness: "I have met the enemy and he is us". Plant Science Bulletin, 48(3), 78-84.


CHAPTER 2: INITIAL DEVELOPMENT AND VALIDATION OF THE PLANT AWARENESS DISPARITY INDEX

Introduction

Plant awareness disparity (PAD, formerly known as plant blindness) is the tendency not to notice plants within one’s environment leading to naïve and anthropocentric points of view such as plants are not important to humans, are boring, or do not do anything (Parsley, 2020; Wandersee & Schussler, 1999). Some of the problems associated with PAD include lack of support for conservation of plants (Balding & Williams, 2016), prejudice among biology teachers against plants and teaching them (Hershey, 1993), zoocauvinism, lack of representation of plants in the media, and even plant neglect in biology textbooks (Hershey, 2002). PAD does not mean that people are incapable of seeing plants, but rather that humans group plants together into a green mass that is often visualized as a backdrop for animals (Wandersee & Schussler, 2001). It also means humans are more likely to be able to name animals. For example, Schussler and Olzak (2008) noted that university students recall more animal names than plant ones, even if they are equally nameable. This phenomenon is a result of a visual cognition bias: human visual systems evolved to notice things that move and/or look like us and therefore do not perceive plants as distinctly as animals (Balas & Momsen, 2014). If students cannot recognize plants in their environments, then this may have a negative impact on students’ reasoning about the importance of plant life to the biosphere and human affairs.

PAD is comprised of four components: attention, attitude, knowledge, and relative interest (Parsley, 2020). Attention is the most notable component in the literature
and refers to how much visual attention students pay to plants in general. *Attitude* is how students feel about plants, particularly in educational settings. *Knowledge* refers to understanding the importance of plants. *Relative interest* indicates how interesting students find plants compared to other organisms, namely animals.

Many have recognized PAD as an issue and have sought to reduce its impacts on students. Interventions surrounding PAD have focused largely on the knowledge and attention components of PAD, attempting to help students understand more about plants in an effort to reduce their levels of PAD (e.g. Frisch et al., 2010; Krosnick et al., 2018; Ward, Clarke, & Horton, 2014; Wyner & Doherty, 2019). This approach can be categorized as a knowledge-deficit model, which has been utilized extensively in the field of science communication (Besley & Tanner, 2011). The knowledge-deficit model refers to the idea that if scientists merely engage with the public more to teach them about science, the public will better understand and support it. However, this model has largely been disproven in the science communication field (Besley & Tanner, 2011). Because the knowledge-deficit model has been disproven in science communication, we hypothesize that the knowledge-deficit model is also insufficient to reduce PAD. Additionally, there is a distinction between this knowledge-deficit model and the knowledge component of PAD. The PAD knowledge component refers specifically to the understanding of how plants are important to the biosphere and to human affairs, rather than more general content knowledge regarding plants. This is an important distinction because instructing students on general knowledge regarding plants (using the knowledge-deficit model) may not be enough to improve their knowledge of why plants are important.
This specific type of knowledge (or lack thereof) regarding why plants matter to humans and the biosphere plays an important role in students’ understanding of plant-related socioscientific issues (SSIs) such as climate change, genetically modified organisms (GMOs), food security, biofuels, and plant conservation. For example, PAD contributes to a lack of knowledge about how illegal wildlife trade affects plant conservation (in addition to animals), which often leads to a lack of protections for plants (Margulies et al., 2019). Krishnan et al. (2019) called for more food and agriculture-related efforts to reduce PAD due to ever-increasing urbanization and a widespread misunderstanding of agriculture. Amprazis and Papadopoulou (2018) have also called for better coverage of plants in primary school curricula to highlight their importance to human welfare and biodiversity.

Many suggestions have been proposed to address PAD in multiple types of learning environments: a Pet Plant Project where university students were asked to grow an unknown plant from seed, using a research-centered botanical curriculum, probing college students’ botanical sense of place, using a hands-on outdoor education program, and using urban trees to bring student attention to plants (Frisch et al., 2010; Krosnick et al., 2018; Wandersee et al., 2006; Ward, Clarke, & Horton, 2014; Wyner & Doherty, 2019). Other approaches include: highlighting teachers’ enthusiasm to increase student interest in plants, capitalizing on students’ interest in herbal drugs and medicinal plants, and seeking out a knowledgeable and friendly plant mentor (Fančovičová & Prokop, 2011; Pany et al., 2019; Strgar, 2007; Wandersee, 1986; Wandersee & Schussler, 2001). While these studies all provide valuable insight into how PAD works and what
interventions have been tried thus far, it is difficult to determine how effective they are when a valid and reliable tool to measure PAD does not exist.

Previously, the Plant Attitudes Questionnaire (PAQ) developed by Fančovičová and Prokop (2010) was used to measure attitudes toward plants, but no instrument exists to measure the entirety of PAD: attention, attitude, knowledge, and relative interest, as described by Dr. Elisabeth Schussler (personal communication). Additionally, this questionnaire was only validated in Slovakian students 10 to 15 years of age and was specifically intended to help determine if having a garden reduced PAD (then called plant blindness). While the instrument is valid and reliable for measuring attitudes toward plants, it was validated in a very specific context with a highly specialized audience and intent, and therefore, is unlikely to be successful in measuring the entirety of PAD in a wider array of contexts.

To address the lack of an instrument that measures all four components of PAD, we have developed the Plant Awareness Disparity Index (PAD-I). The PAD-I is designed to evaluate undergraduate students’ level of PAD based on the four components of PAD. The development of this instrument is also a way to determine whether these four theorized components can operate as subscales within the PAD-I, and whether these components are supported by the data collected. Here we describe the development and validation of the instrument and provide case studies to show how students’ PAD-I scores are indicative of the extent of their PAD. To do this, we developed the following research questions:

1. To what extent does the PAD-I demonstrate face validity?

2. To what extent does the PAD-I demonstrate concept validity?
3. To what extent does the PAD-I demonstrate structural validity?

**Methods**

**Initial Development of the PAD-I**

To develop the Plant Awareness Disparity Index (PAD-I) we considered each of the four components of PAD individually and created items that would address each component. We used the Plant Attitudes Questionnaire (PAQ) as a reference for how plant-related attitude items could be written but decided to create our own items that would address attitudes towards plants (Fančovičová, & Prokop, 2010). While the PAQ is valuable in that it measures how students feel about plants and what their attitudes toward plants are, PAD is about more than attitude. Therefore, we opted to create an instrument that would measure all the facets of PAD. We created items that aligned with all four components based upon conversations with Dr. Elisabeth Schussler and previous findings within the literature. We went through multiple rounds of revisions before we settled on a semi-final version which we sent to Dr. Schussler as our expert reviewer for clarity and soundness of ideas. After incorporating her edits, we came to the first version of the PAD-I which included eight items about attitude, eight items about knowledge, six items about relative interest, and six items about attention, for a total of 28 items.

We used a Likert-style scale consisting of, “Completely Disagree, Somewhat Disagree, Somewhat Agree, and Completely Agree,” as answer options. We omitted the choice of a neutral option due to the possibility that students would choose it too often (reflecting their lack of interest in plants). Instead, we wanted to encourage students to think deeply about each item and determine how they felt about it. Positive and negative
items were used in the instrument, and the negative items were reverse scored. We scored, “Completely Disagree,” as one, “Somewhat Disagree,” as two, “Somewhat Agree,” as three, and “Completely Agree,” as four (except where items were negative and reverse-coded). The minimum score was 28 if students answered all items with a negative (plant-unaware) answer, and the maximum score was 112 if they answered all the items with a positive (plant-aware) answer. We included a quality control item that instructed the respondent to select the answer, “Somewhat Agree.” If the respondent answered this item incorrectly, we removed the data for that participant, as this indicated the participant did not pay attention while answering the survey.

**Survey Pilot and Proof of Concept**

**Context and Participants**

Our study took place over two trimesters and included all students in an undergraduate botany course at a small Midwestern university. Thirty-eight students (100%) consented to participate in the first trimester and 40 students (100%) consented to participate in the second. The course consisted of primarily junior-level (3rd year) undergraduate students, was required for all biology majors, and lasted ten weeks as the university operated under a trimester schedule. While the course was introductory in skill level and largely lecture-based, the professor also used a mixture of class discussion, the Socratic Method, PowerPoint slides for students to add information to, worksheets, exposure to primary literature that also involved group activities, and debates that required preparation outside of the classroom. The topics covered included plant anatomy, morphology, physiology, and diversity. Basic ecology
was a programmatic (departmental) mandate that was woven throughout the
course. Course work included two-unit exams (consisting of a mix of multiple choice,
fill-in-the-blank, drawing/labeling drawings, short answer, and short essay questions),
class participation and assignments, a class discussion with worksheets and reflections on
the book *Walden Warming* by Richard B. Primack, and a final exam. The final served as
a third unit exam with an added section covering material from the entire course. Like
the two-unit exams, the format was a mix of question types. The course also required
concurrent enrollment in a weekly, two-hour long botany lab, which constituted 20% of
the overall grade in the course and included three lab quizzes and an inquiry-based
research project.

**Data Collection**

All methods were approved by the University of Memphis IRB. In the pilot study
we utilized a mixed methods research design by administering the survey as a pre/post-
test (n=60 across two trimesters) and collecting interview data (n=10 across two
trimesters) to establish face validity and proof of concept during the pilot study. The
survey was administered at the beginning and end of two trimesters. Interview
participants were selected based on having a range of scores on the PAD-I so as to probe
student ideas about plants from differing levels of PAD. In the interviews, we asked
students about different concepts related to PAD (e.g., plant mentors, positive and
negative experiences with plants, and memories or experiences surrounding plants) as
previous studies have indicated these are important factors that contribute to whether or
not a student demonstrates PAD (Parsley et al., in review). In the second trimester, we
added questions regarding the extent to which students had trouble understanding the
survey or answering any of the questions, and if they had any suggestions for how to make the survey more accessible and clear.

**Data Analysis**

All collected data were blinded with a random ID number before analysis. Students received the same ID number for both surveys and interviews. All names used in the results section below are pseudonyms. To evaluate the PAD-I, we calculated averages for all four subscales within the PAD-I for all of the students. Each subscale average had a range of one to four, as each item within the subscales were scored from one to four. We calculated subscale averages by adding all the item scores within each respective subscale together and dividing by the number of items within that respective subscale. The highest possible overall score for the instrument was a 112, the lowest score possible was 28. We also completed a one-way repeated measures ANOVA for the overall summed PAD-I score, and all four averaged subscales within it. We then repeated the ANOVAs for the second trimester of data in our study.

To answer research question 1, “To what extent does the PAD-I demonstrate face validity?”, we used descriptive coding and specifically looked for answers to our interview questions indicating that there were problems with the instrument, and whether the participant had any suggestions for how to improve the instrument in case changes needed to be made to the survey to make it more understandable (Miles et al., 2014). We also collected answers that indicated that the instrument had sound face validity and made sense to the respondents.
To answer research question 2, “To what extent does the PAD-I demonstrate concept validity?”, we created mini case studies of all the participants to compare their pre- and post-PAD-I scores to their interview data. This allowed us to demonstrate that students with a range of PAD-I scores also demonstrated a range of PAD in their interviews, providing evidence for concept validity. We used descriptive coding again to look for specific examples of PAD (or lack thereof) within each interview (Miles et al., 2014).

Pilot Study Results

Survey Results

Note that a higher score on the PAD-I indicates a decreased level of plant awareness disparity (or an increased level of plant awareness), while a lower score indicates a higher level of plant awareness disparity (or a decreased level of appreciation for plants). In trimester 1, the PAD-I score average increased significantly from 82.3 to 85.2 \((p = 0.012)\) The Attention subscale increased significantly from 2.85 to 3.00 in trimester 1 \((p = 0.019)\) as did the Knowledge subscale with a pre-test score of 3.42 and a post-test score of 3.57 \((p < 0.001\), see Table 1).

This trend was continued in trimester 2, with a significant increase in overall PAD-I scores from 80 to 84.2 \((p < 0.001)\). Three of the four subscales also increased significantly. Attention increased significantly from 2.75 to 2.92 \((p = 0.017)\), knowledge subscale increased from 3.39 to 3.60 \((p < 0.001)\) and relative interest subscale increased from 2.06 to 2.18 \((p = 0.030; \text{ see Table 2})\).
The category with the largest effect score in both trimesters was knowledge, indicating that many students felt significantly more confident in their knowledge of the importance of plants across both trimesters. Attention had a low effect score in both trimesters, indicating a smaller change in score for this concept (as compared to the other concepts and the survey overall). In the second trimester, relative interest had the lowest effect score, compared to the first trimester where there was no significant increase in the relative interest scores. It appears that relative interest changes the least when considering changes from pre- to post-test. This indicates a relative stability in student interest, regardless of how knowledge or attention may change over time. Attitude also did not change significantly, indicating that it tends to be stable along with relative interest.

Table 1.

*Pre/post PAD-I scores for trimester 1*

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-test mean</th>
<th>Post-test mean</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>Partial Eta Squared (Effect size)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAD-I</td>
<td>82.3</td>
<td>85.2</td>
<td>28</td>
<td>7.261</td>
<td>.012*</td>
<td>.206</td>
</tr>
<tr>
<td>Attitude</td>
<td>3.12</td>
<td>3.22</td>
<td>28</td>
<td>2.764</td>
<td>.108</td>
<td></td>
</tr>
<tr>
<td>Attention</td>
<td>2.85</td>
<td>3.00</td>
<td>28</td>
<td>6.235</td>
<td>.019*</td>
<td>.182</td>
</tr>
<tr>
<td>Relative Interest</td>
<td>2.14</td>
<td>2.13</td>
<td>28</td>
<td>.029</td>
<td>.866</td>
<td></td>
</tr>
<tr>
<td>Knowledge</td>
<td>3.42</td>
<td>3.57</td>
<td>28</td>
<td>16.715</td>
<td>&lt;.001*</td>
<td>.374</td>
</tr>
</tbody>
</table>

* indicates significance at the 0.05 level
Table 2.

*Pre/post PAD-I scores for trimester 2*

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre mean</th>
<th>Post mean</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>Partial Eta Squared (Effect size)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAD-I</td>
<td>80.0</td>
<td>84.2</td>
<td>35</td>
<td>21.039</td>
<td>&lt;0.001*</td>
<td>.375</td>
</tr>
<tr>
<td>Attitude</td>
<td>2.99</td>
<td>3.05</td>
<td>35</td>
<td>1.260</td>
<td>.269</td>
<td></td>
</tr>
<tr>
<td>Attention</td>
<td>2.75</td>
<td>2.92</td>
<td>35</td>
<td>6.30</td>
<td>.017*</td>
<td>.153</td>
</tr>
<tr>
<td>Knowledge</td>
<td>3.39</td>
<td>3.60</td>
<td>35</td>
<td>45.546</td>
<td>&lt;0.001*</td>
<td>.565</td>
</tr>
<tr>
<td>Relative Interest</td>
<td>2.06</td>
<td>2.18</td>
<td>35</td>
<td>5.086</td>
<td>0.030*</td>
<td>.127</td>
</tr>
</tbody>
</table>

* indicates significance at the 0.05 level

**Interview Results: Face Validity**

To determine face validity, we asked interview participants in trimester two about any issues they had when taking the PAD-I. Four out of five interview participants responded that the survey was clear and made sense to them, and that they would not make any changes. However, Brenda offered crucial feedback when she answered, “Well, I mean for number three it says, "I have taken plant courses for my degree." [College] only offers one. We have [inaudible] and then I think we did have a more in-depth botany class, but we don't offer anything else besides environmental courses.” This indicated that the item regarding plant courses would not work as well for programs with
few plant science offerings, and perhaps was not accessible for some students because of this. We opted to remove this item from the second iteration of the instrument (between the two rounds of exploratory factor analysis (EFA).

**Interview Results: Concept Validity**

In Chapter 3, we also analyzed these interviews to specifically look for the four components of PAD and found that students spoke both positively and negatively about plants in their interviews (Parsley et al., in review). Below we demonstrate what these positive and negative comments looked like, and how they corresponded to higher and lower levels of PAD.

**Nick, Trimester One**

Nick had the highest PAD-I score of the class with a score of 100 out of 112. When asked why he thought he got this score, Nick answered,

Well, I think it has to do with the things I was saying earlier, just because of my interests within nature. So, I think it's become more, I don't know, of a passion as I've grown. I was never really on the complete major environmental track. I was pre-med, but then there was a switch and that felt right for me, so I kind of went with it. I have been doing it since then and enjoying that, so I think that's why I probably got that 100, because I really agree with a lot of these things.

When asked what prompted this switch in majors, Nick replied,

There was an awakening kind of thing. I should be doing what I love, instead of something that I could enjoy but wouldn't enjoy as much. College is expensive and I want to come here, and I want to be able to make money when I leave and
sufficient enough to take care of myself and anyone else I would need to take care of or want to. So that was my idea that way, but through talking to people, I realized that although, yeah, the doctors do make a lot of money ... I was like, that's not the reason why I should be doing this. I should be doing this because I love it.

Nick’s choice to switch majors is an example of his lack of PAD as it was driven by a desire to have a career that he truly loved because it involved nature and being around plants, rather than one that would make him money. Nick’s love of nature led not only to a lowered level of PAD but also to a change in his career. However, this is not the only demonstration of his interest in plants, as he recounted:

My first interest was in junior high when we had a ... Essentially it was a group of staff from my middle school that took a group of kids weekly on some kayaking or canoeing trip. Then from there, I got interested in nature. So, it's been a build from there into college.

Nick spoke about his experiences in middle school leading him into his current major and how this love of nature inspired that transition. He also brought up his mother as a plant mentor, and explained:

I guess my mom always had a “stay outside until it's night” kind of idea. So we had to have our fun being in nature, so it just became part of my life and not like, oh, we live inside and when we go outside, it's a different place. But we spent a lot of our time outdoors.
His mother’s approach of living life outside and not just regarding it as a separate space increased Nick’s experiences with nature, which in turn led to his enjoyment of the outdoors. When asked about his current relationship with plants, Nick replied:

I think since then, it's changed. It's come more to I want to understand plants more and understand nature more, instead of just experience it. Still experience it though because I have a love for it. I want to be in it, I want to learn about it, I want to know more about it. I think it's just changed from a, oh, let's go outside and whatever to I'm going on hikes, I'm noticing, oh, this species of whatever. Oh, that's an invasive species and stuff like that.

Nick noted that while his desire to be around plants has not changed, his desire to learn more about them has increased and that because of this he is able to look at plants in a more specific light when he is outdoors.

All of these ideas together indicate that Nick does not demonstrate a significant amount of PAD, and this is reflected in his PAD-I score. When asked if he thought anything about plants was boring, Nick responded that he could not think of anything, further demonstrating his low PAD levels. At the end of the trimester, Nick’s score stayed at 100, indicating that his PAD levels did not change (despite his new knowledge of plants from his botany course), likely because of his already-existing appreciation for plants.

Ashley, Trimester One

Ashley had the lowest score of the class on the PAD-I with 68 out of 112. Due to technical difficulties, Ashley’s response to the question of how she thought she got her
score was not recorded. However, when asked how her opinions of plants had changed since the survey, she answered,

Since I've taken botany, I've learned a lot more information about plants. Physiology, anatomy, I have a lot more respect for the different processes that I didn't know existed. It's a lot more complex than I thought it was. I thought it was very simple compared to animal physiology. They're two different categories but it's more complex than I thought it was.

Ashley spoke of how she entered her botany course with misconceptions that plants were simpler than animals or performed fewer physiological processes. These ideas changed in the time between taking the PAD-I and completing the interview, but they may have contributed to her low score on the PAD-I at the beginning of the trimester.

When asked about a plant mentor, Ashley noted that she did have pleasant memories of being around plants and her plant mentor (her father):

Most of my father's side of the family are farmers, they own farms. They plant corn, soybeans, things like that. In the Chicago area, we got the giant garden where we plant tomatoes, beans, bell peppers, all kinds of plants. My father and I and all of my siblings would always plant a garden every year. Not specifically about plants, but the best way to garden, I guess, so you get the best product.

Even though Ashley had a low score on the PAD-I, she does have pleasant memories of being around plants as a child in the context of gardening and agriculture. However, when asked what her current relationship with plants was like, she answered,
It's not very good like it used to be. I don't have any plants; I don't garden anymore. My whole life is just work, school, work, school and sometimes sleep.

So, I don't have ... I would like to have a garden again. I would like to do those things again, but I just don't have the time to dedicate into that.

Her lack of time availability to spend enjoying plants in the way that she used to (via gardening) is the determining factor in her current relationship with plants, which demonstrates a possible reason for her lowered PAD-I score. Additionally, when asked if she thought anything about plants was boring, she responded,

Where does the list start? I don't know if I have a specific answer on that. I think the most boring part so far is trying to memorize all of the new terminology and the new words that I've never seen before that are involved in anatomy and physiology with plants. I think that's the most boring, time consuming part of it.

When asked why this was boring to her, she answered:

A lot of the words I've never seen before. With human anatomy or physiology, I've seen those words before, I know what they mean. So, it was very easy to study and learn different processes. With plants though, I've never seen these words before, so it took a longer amount of time to learn anatomy or different processes in plants. Compared to my other biology classes.

The combination of previous misconceptions of plants, a poor current relationship with plants, and a distaste for the jargon associated with learning about them seems to have discouraged Ashley. This explains her low score of 68 on the PAD-I, though it could be much lower (the lowest possible score is 28). The fact that her score was not
lower may be explained by her previous positive attitudes toward, and experiences with, plants. It appears that previous experiences alone are not enough to maintain high plant awareness, and that these need to be supplemented with a continuation of positive experiences and relationships with plants. At the end of the trimester, Ashley scored a 67 on the PAD-I, which was one point lower than her original score. The relative consistency in her score likely demonstrates that knowledge of plants gleaned from her botany course was not enough to improve her level of PAD.

**Tiffany, Trimester Two**

Tiffany scored a 97 out of 112 on the PAD-I, which was the highest score in the class for that trimester. When asked why she thought she got this score, Tiffany answered,

Well, I've grown up in ... My backyard is basically a forest, so we do a lot of outdoor activities, and my parents always ... made us play outside, and so I've always been around plants. And my mom's a big plant lady, so she would bring me to the garden store when I was younger all the time. So, I've kinda had that exposure and background.

Tiffany cited being outdoors a lot and learning from her mother as a reason for her high score, a similar story to the one Nick told in trimester one. This makes sense as both students received the highest PAD-I scores in their respective trimesters. When asked if she had a plant mentor growing up, Tiffany responded,

I would definitely say my parents, my mom and my dad. My mom's very into gardening and she has a lot of house plants and stuff. And then my dad, he does a
lot of outdoors-y stuff and hiking, and he's pretty knowledgeable about that kind of thing. So when we'd go on hikes in the woods, my dad would pick up a leaf and he would show it to us, and be like, "This is an oak leaf, and you can tell because of the structure, or the curve," you know, edges, or whatever, and then, "This is a maple, and you can see it's pointy," or like shagbark hickories, "Oh, you can see it's like shaggy," and just stuff like that. And then my mom, we would go to a garden store and be picking out plants to plant in our various gardens. And I'd be like, "Why can't you plant ..." and she was like, "Well, we can't do that one," and she'd explain, "Well, this is for the sun, but this is ... We're trying to find stuff for a shade garden," and things like that. So, understanding different environments plants thrive in. And then we had indoor plants, like, "Oh, this is ... They're used to warmer climates, we can't plant that outside," kind of thing.

Tiffany speaks in depth about both her parents and the types of information she learned from them regarding plants. Her father taught her information about plant morphology and identification, while her mother taught her about gardening and caring for house plants. This combination of different types of plant knowledge could be another reason for why she scored so highly on the PAD-I. When asked what her current relationship with plants is like, Tiffany replied,

Well, I absolutely love them. I think it's actually grown since I was younger. I'm absolutely loving my botany class right now. I'm very much the type of person that would rather go camping than go to a luxury hotel, and I love being outside. Whenever I get the chance, I walk somewhere. I think that I've definitely grown in my appreciation for plants too as I have learned more about them. And yeah, I
definitely love being around them and learning more about them. And I always like to do more of it when I get the opportunity.

Tiffany talked about how her love for plants has only grown since she was young, and notes that the more she learns about them, the more she wants to learn. This positive feedback no doubt decreased her level of PAD. When asked if she thought anything about plants was boring, Tiffany responded,

I guess I'm more of an animal fan. If somebody would be like, "Do you like animals or plants better," it would probably be animals, like I think it's really cool how plants work and I enjoy learning more about how they interact in an ecosystem, 'cause I learned last year they can communicate with each other, and they do kind of move with the sun and stuff. But generally, I think plants are a little bit more boring because they aren't interactive with people, generally speaking, or as far as I know, or I guess they're less interactive than other things in an ecosystem. They just kinda sit there. But I guess in that aspect, they're kind of boring, but I think the more I learn about them, the more I get excited about them 'cause there's a lot of stuff I don't know about plants.

Despite her love of plants, Tiffany admits that she finds them less appealing than animals because animals move and interact with humans more so than plants. Even so, she still admits that there are things she does not know about plants, and that she recently learned they can communicate with one another. The combination of positive experiences with plant mentors, a continued interest in plants, and learning new information about them likely contributed to her PAD-I score. Tiffany’s score also stayed the same at the
end of the trimester (97) just like Nick’s did in trimester one. This indicates that her newfound knowledge of plants did not impact her level of PAD.

**Brendon, Trimester Two**

Brendon scored a 64 out of 112 which was the lowest score of the class for that trimester. When asked why he thought he received this score, Brendon answered,

While I do enjoy nature, I'm more of a microbiologist. [Botany is] just [inaudible] required for my major. I don't per se care about plants. I don't have a background in plants outside of this course, speaking like academically. I would say that's probably why, I just don't have much of an affinity towards plants outside of like soil microbiology.

Brendon describes that he has more of an affinity for microbiology than plants, and that he does not have an affinity for, or care about, them much. This is likely a reason for his low PAD-I score. When asked if he had any plant mentors growing up, Brendon responded,

I don't know if I really have one per se, I would say my Scout master of course taught me a lot about plants. I can understand like these plants you should stay away from. These plants they grow fruit you can eat, and things of that nature. My ex-girlfriend's mom, we're really good friends, and she's really into like plant conservation. I'd say she is, because you'll go hiking with her and she'd be like, "Oh, these plants are invasive", and talk about the environment and the ecosystem. Outside of that maybe I would say my botany professor, he's taught
me a lot. I would say [professor] has probably taught me the most, he's definitely taught me a lot about the actual structure of plants.

While Brendon does identify a few experiences that have to do with a plant mentor, it does not appear he has a stable long-term relationship with one. He cites his ex-girlfriend’s mother and his professor, the latter of which is required to instruct students about plants. This alone does not disqualify the professor as a plant mentor, but it does have an impact upon the relationship between Brendon and the professor. When asked what his current relationship with plants was like, Brendon replied,

I eat occasional berries and fruit but that's it. Obviously, I'm in a botany class, so I'm learning about them but most of it is based in food. I don't really have time to garden or do any conservations efforts with like school and work and everything going on, so it's pretty limited.

Brendon notes that his current relationship with plants is quite limited, as it is mostly about the food he eats. This is similar to Ashley in trimester one who also had a strained relationship with plants as she lacked the time and availability to spend time around them. When asked what he thought was boring about plants, Brendon responded,

What's boring about them, I guess they don't do things, like animals do things. Like yes, plants evolve, they grow thorns, they modify their weeds, they get bigger, smaller, things of that nature. But I just don't think of plants in the same way. I look at a plant I'm like, oh, it's a plant. Also, it's like maybe you have a cactus with like a Venus fly trap, oh, that's crazy. But like looking at animals you have rats, then you can have a gorilla, those are vastly different things. I guess
they're not mobile. I can't interact with a plant and it per se interact back with me. I can go for a run with my dog, or things like that. I guess it's just biomechanics is an interest of mine. How do animals move, how do they do the things they do? Why do they do them in that fashion? How do they evolve to do them? That's an interest of mine, like birds flying is crazy. Their bodies evolve based on physics to allow them to fly. Things like that are just of interest to me. That being said I am also into microbio, which like [inaudible] do things, so kind of two-fold.

Brendon notes that a lack of motion in plants is one reason why he finds them boring, as he has a specialized interest in animal biomechanics. He also likes that animals can interact with humans more so than plants. This is a similar answer to the one Tiffany gave in the same trimester. However, Tiffany had many positive experiences with a stable plant mentor relationship, and that trend continued into her current relationship with plants. This is likely the reason for Brendon receiving the lowest score, as he does not have a long-term plant mentor relationship or a positive current relationship with plants. However, Brendon was the only participant in both trimesters to improve his PAD-I score, as his post-test score increased to a 76. This indicates that for Brendon, something about his experiences in the botany course did improve his level of PAD-I. This seems to be because his attention sub-score increased dramatically from 9 to 17 points. His knowledge score also increased from 22 to 24, while his relative interest actually decreased from 12 to 11, and his attitude increased from 21 to 24. Of all the sub-scores, his attention changed the most, indicating that his experiences in the botany course mostly affected his attention to plants.
It is clear in both trimesters that positive experiences with plants, both past and present, play a large role in whether or not a student exhibits more PAD. However, in both students with the lowest scores, previous positive experiences did take place, but they seem to have been overpowered by lack of current experiences and finding plants boring. It is worth noting that Nick indicated no negative experiences with, or opinions of, plants, while Tiffany did feel that plants were sometimes boring due to their lack of movement. This likely explains why Nick received a higher score than Tiffany did, indicating that the PAD-I is potentially capable of delineating amongst differing levels of PAD even at high or low ends of the scoring spectrum.

**Exploratory Factor Analysis: Round One**

**Methods**

To determine structural validity, we conducted two rounds of exploratory factor analysis, which allowed us to determine the factor structure of the instrument and whether it was stable. In the first round of exploratory factor analysis (EFA), we used a quantitative factor analysis design and sent out emails through two existing science education listservs, the Society for Advancement of Biology Education Research (SABER) and National Association for Research in Science Teaching (NARST), to recruit instructors who were willing to have their students participate. The PAD-I survey was administered via Qualtrics with a consent form at the beginning. Students spent approximately 15-20 minutes total on the survey, and our target population was undergraduate students taking a biology class. We received a total of 1,231 respondents
for the PAD-I which came to 1,062 after data cleaning to remove any incomplete responses or any participants that did not respond correctly to the quality control item.

We performed a preliminary reliability analysis on the PAD-I to determine the internal consistency of the instrument. Our analysis yielded an acceptable Cronbach’s alpha score at 0.85. We analyzed the results of the first round of EFA using a maximum likelihood factor extraction with direct oblimin rotation within the psych package in R (Revelle, 2019). We used the fa.parallel function within the psych package to generate a scree plot and the accompanying recommendation of how many factors should be extracted for the analysis (See Appendix A). Maximum likelihood extraction and direct oblimin rotation are often used for confirmatory factor analysis (CFA) which is used to confirm the hypothesized factors of an instrument. However, this methodology has also been used to create factor loading scores that can then be transformed into item discrimination parameters for use in item response theory (IRT) and Rasch analyses that will give us insight into how individual items are operating within the instrument (Revelle, 2019).

Results

Our first EFA results for the PAD-I revealed a six-factor model, differing from the original hypothesized four-factor model (attitude, attention, knowledge, and relative interest). The six factors were: Caring for or Investment in Plants (three items), Necessity of/Importance of Plants (four items), Plants Better than Animals (five items), Animals Better than Plants (three items), Attention to Food Plants (three items), and Positive Affect (five items). Names for the factors were determined by examining what items loaded onto each factor and observing what concepts or ideas these items had in
common. All items loaded onto their respective factors with a score of 0.3 or higher as required for EFA ($\chi^2 = 666.92$, df = 225, $p < 0.01$, TLI = 0.917, RMSEA = 0.043).

The six factors of the PAD-I still aligned well with the original attitude, attention, knowledge, and relative interest components of PAD (see Figure 1), so we proceeded with edits to remove any items that did not load onto a factor, as well as clarify and reword items that loaded poorly onto a factor. We also added a newly hypothesized factor called, “General Attention,” which includes three items, two of which were recycled from the original PAD-I instrument and one item that was newly created. We did this because the only attentional factor that was gleaned from factor analysis was attention to food plants, which may point to a tendency for students to only notice plants in the context of what they do for humans.

![Figure 1. Alignment of preliminary hypothesized factors from factor analysis with previously hypothesized factors based on the four components of PAD.](image)

We added the general attention factor to compare the two to determine if this was the case in the next round of analysis. After adding the new factor, we went through more rounds of revisions with Dr. Schussler before settling on the second version of the instrument. The second version was 30 items long with each factor containing three to six items per factor. There were three items in Caring for or Investment in Plants, six in
Necessity of Plants/ Importance of Plants, six in Plants Better than Animals, three in Animals Better than Plants, four in Attention to food plants, five in Positive Affect, and three in the newly-added General Attention factor. This change in length meant that the new minimum score that could be obtained with the instrument was 30 if student chose all negative (plant-unaware) answers, and 120 if the student chose all positive (plant-aware) answers.

Exploratory Factor Analysis: Round Two

Methods

In the second round of EFA, we again sent out emails through the two existing science education list serves that we used for the first round of EFA (SABER and NARST) to recruit instructors who were willing to have their students participate. We cleaned the data to remove any incomplete responses or any responses that did not respond correctly to the quality control item which asked students to select, “Somewhat agree,” as their answer in the first round of EFA. Before cleaning, we had 700 responses and after cleaning we had 553 due to the large amount of incomplete responses and some participants who did not answer the quality control item correctly.

We used another maximum likelihood factor extraction with direct oblimin rotation within the psych package to determine if the six-factor model is still appropriate (Revelle, 2019). However, this time we tested a few different models based on feedback we received from the second EFA indicating that a few of the items were not loading as we had hypothesized after the first round of EFA. Of the four models we tested, two included seven factors and two included six. We reviewed goodness-of-fit indices to
make our decision about the model that would best fit the data. The variations in the models were in the number of factors (six or seven) and which items we removed (items that loaded on the wrong factor, and items that did not have a loading score of 0.3 or higher).

**Results**

The scree plot originally generated using the `fa.parallel` function in *psych* indicated that our instrument had seven factors (See Appendix B). These factors were almost identical to the factors we found at the end of EFA round one, with the exception of a few items that loaded onto different factors than they had originally. We decided to test another seven-factor model without these items, a six-factor model without these items, and a six-factor model that excluded a few extra items that did not load (see Table 3). After removing items 13, 14, and 20, the scree plot indicated we should only use a six-factor model (See Appendix C). However, we decided to test a seven-factor version as well to see how it would affect loading scores and cross-loadings.
A comparison of the four models tested during EFA study two using goodness-of-fit indices.

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>$\chi^2$</th>
<th>df</th>
<th>TLI</th>
<th>RMSEA</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Seven factors; no items removed</td>
<td>474.98</td>
<td>246</td>
<td>0.936</td>
<td>0.042</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Two</td>
<td>Seven factors; 13, 14, and 20 removed</td>
<td>331.48</td>
<td>183</td>
<td>0.951</td>
<td>0.039</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Three</td>
<td>Six factors; 13, 14, and 20 removed</td>
<td>426.46</td>
<td>204</td>
<td>0.934</td>
<td>0.046</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Four</td>
<td>Six factors; 13, 14, and 20-22 removed</td>
<td>301.73</td>
<td>165</td>
<td>0.955</td>
<td>0.04</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Note: TLI = Tucker Lewis Index; RMSEA = Root Mean Square Error of Approximation

The scree plot that was generated after items 13, 14, and 20 were removed indicated that a six-factor model would be a better fit for our data, so we moved forward with the third and fourth model. A scree plot was generated for the fourth model which removed items 13, 14, and 20-22 indicated that a six-factor model was still the best choice (See Appendix D). We eventually decided the fourth model would be best, as it was the one that had the best goodness-of-fit scores. Every item in this model loaded with a score of 0.3 or above (see Table 4). Model four removed the Attention to Food Plants factor entirely, and instead focuses on one factor named Attention toward Plants (see
Figure 2). This new factor combines items from the previous General Attention and Attention to Food Plants factors to create a well-rounded representation of the fact that attention to all types of plants is an important component in the PAD-I. The rest of the factors remained the same across all four models, which indicates that the factor structure is very stable. In the final version of the PAD-I there are 25 items, which also makes it easier to score as the scale is 25 to 100 and can easily be transformed into a percentage by subtracting 25 from the final score and dividing this by 75. The six factors of the PAD-I still align very well with the original four components of PAD (see Figure 2). Two of the original four components break into two factors (which can be thought of as sub-categories of these components): attitude breaks into “Positive affect toward plants” and “Caring for or investment in plants” while relative interest breaks into “Plants better than animals” and “Animals better than plants.” We still refer to the original four components conceptually because the results of the factor analyses align with these components, but in the case of the instrument itself, we use the six-factor terminology as that is what we found in the analyses.

<table>
<thead>
<tr>
<th>Original four components of plant awareness disparity</th>
<th>Attention</th>
<th>Attitude</th>
<th>Relative Interest</th>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention toward Plants (Includes Food and Non-food Plants)</td>
<td>Positive Affect toward Plants</td>
<td>Caring for or Investment in Plants</td>
<td>Plants Better than Animals</td>
<td>Animals Better than Plants</td>
</tr>
<tr>
<td>(Understanding the) Necessity or Importance of plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2. Alignment of EFA-reinforced six-factor model with original four components of PAD.*
Table 4.

*Items and Factor Loading Scores of the Final Version of the PAD-I*

<table>
<thead>
<tr>
<th>Item</th>
<th>Caring for/Investment in Plants</th>
<th>Necessity of Plants</th>
<th>Animals</th>
<th>Positive Affect</th>
<th>General Attention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I enjoy caring for house plants.</td>
<td></td>
<td>0.725</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. I enjoy caring for plants in an outdoor environment</td>
<td></td>
<td>0.897</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. I care about the plants that are in my neighborhood.</td>
<td></td>
<td>0.454</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Plants are important because they help reduce the effects of climate change.</td>
<td></td>
<td>0.562</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Plants are an important source of food for the world. 0.708

6. Plants are important to ecosystems. 0.800

7. Plants are important because they are a source of oxygen. 0.711

8. Plants are important because they are a source of new medicines. 0.602

9. Animals need plants in order to survive. 0.719

10. I think plants are more useful to learn about than animals. 0.691

11. I think plants are more interesting to learn about than animals. 0.674
12. If I had to choose, I would rather keep houseplants than animal house pets. 0.431

13. When I go outdoors, I am more likely to notice the individual plants around me than any animals in the environment. 0.335

14. Learning about animals interests me more than learning about plants. 0.762

15. Animal conservation is more interesting to me than plant conservation. 0.711

16. I think animals are more interesting than plants, in general. 0.838

17. I enjoy going outdoors because of all the plants in the environment. 0.408
18. I would enjoy visiting a botanical garden.

19. I have a lot of good memories about plants.

20. Being around plants makes me feel happy.

21. In general, I think plants are very interesting organisms.

22. I notice the crops that are grown near where I live.

23. When I take a walk outside, I notice the plants around me.
24. When I am in a wooded area I notice individual plants, not just the forest as a whole.

25. I notice all the plants in my environment, not just those that I eat.
Discussion

Our instrument measures PAD as first described by Wandersee & Schussler (1999), and it specifically incorporates the four components: attitude, attention, knowledge, and relative interest (Parsley, 2020). Our results indicated that attention toward plants is a very important component of PAD, and this finding aligns with that of Schussler and Olzak (2008) and Balas and Momsen (2014). The final model of the PAD-I includes six factors: Caring for or Investment in Plants, Necessity of Plants/Importance of Plants, Attention toward Plants, Positive Affect toward Plants, Plants Better than Animals, and Animals Better than Plants. The evidence would indicate that these factors continue to align well with and support the original four theorized components of PAD as described by Dr. Elisabeth Schussler, as two of the original four components can be broken down into further subcategories when considering the factor structure of our instrument. In other words, PAD has four components that align conceptually with the six factors of the PAD-I.

This survey builds upon some of the work done in developing the Plant Attitudes Questionnaire (PAQ) by incorporating attitudes toward plants, and it does so by tying in the rest of PAD’s components into a more holistic view of PAD (Fančovičová & Prokop, 2010). Our results further support the idea that people who are more invested in plants or care for them in some way have decreased PAD (Balding & Williams, 2016). This may also help students overcome their prejudice against plants, and pre-service teachers exposed to this survey will have a better understanding of their level of PAD as well, potentially improving their botany teaching (Hershey, 1993; 2002). For example, if pre-service teachers are not only exposed to the idea of PAD, but actually know how much...
PAD they demonstrate (via this instrument) they can potentially adjust for this when designing curricula for their future classes and intentionally teach with more plants in these curricula.

The development of this tool will allow instructors to measure how well their interventions work in reducing student levels of PAD. More specifically, this survey could be used to reinforce the findings of Schussler and Olzak (2008) that university students recall more animal names than plant ones, even if they are equally nameable. If researchers were to investigate PAD using both a picture-based assessment such as that used by Schussler and Olzak (2008) and combine it with this self-reported PAD-I, they could get a more robust understanding of PAD. This understanding would not only include the attentive state of PAD (as evidenced by the picture assessment) but also the affective states of PAD (as evidenced by the PAD-I). Now that there is a valid and reliable survey to measure PAD, we can begin to design studies that quantitatively test whether previously described learning interventions work with university students (Frisch et al., 2010; Krosnick et al., 2018; Wandersee et al., 2006; Ward, Clarke, & Horton, 2014). The PAD-I will also allow for comparative studies to determine how PAD changes over time.

The results of our study not only have the potential to change how instructors and researchers measure PAD, but also how they approach it conceptually. We provide structural data that support the original four-component model of PAD described by Parsley (2020), as the PAD-I consists of six factors that align conceptually with these four components of PAD. It can be said that our instrument breaks down two of the four components (relative interest and attitude) into two, more granular sub-categories.
Regardless, this is the first time that data have been used to support the hypothesized four components of PAD.

Additionally, we provide evidence that a knowledge deficit model of PAD is not sufficient. In the pilot study, the significant change in score with the largest effect size in both trimesters was knowledge, indicating that more students felt significantly more confident in their knowledge of plants across both trimesters. However, the lack of a similar pattern in attention, relative interest, and attitude indicates that while botany courses do affect students’ knowledge, they may not necessarily have an impact on the other three components of PAD. This indicates that relying on a knowledge deficit model of PAD is not sufficient and will not impact the rest of the problems that comprise PAD.

The knowledge deficit model originated in science communication research and refers to the idea that if scientists simply teach the public more about science, the public will come to appreciate it more. However, this model is outdated and has largely been disproven in the science communication community (Besley & Tanner, 2011). Unfortunately, this is still one of the driving models in the PAD community, as several interventions surrounding PAD rely on getting students to understand more about plants (e.g. Frisch et al., 2010; Krosnick et al., 2018; Ward, Clarke, & Horton, 2014; Wyner & Doherty, 2019). While knowledge is a component of PAD, it is the specific understanding of why plants are important to the environment and to people that is the most important type of knowledge in this scenario. Therefore, we suggest more interventions that better integrate this type of knowledge with something that will also engage student interest in, attitude, and attention toward plants. It is important to consider all four conceptual components of PAD (attitude, attention, knowledge, and relative
interest) when designing these interventions to better get at the entirety of a students’ PAD.

This instrument will be useful for those who are interested in the problem of PAD and how we can find concrete ways to address it both in and outside of the formal classroom setting. PAD has been shown to begin and continue throughout the K-12 education experience, and it is for this reason that we intend to validate the instrument for a younger population next. Partnerships with informal education venues such as science centers, botanical gardens, and environmental education programs will be able to determine if a particular informal education approach differs in effectiveness compared to more formal education approaches, and as such, we will be validating the instrument in these settings too. Doing so will allow researchers to measure whether their interventions or outreach programs are improving PAD (Fančovičová & Prokop, 2011; Pany et al., 2019; Strgar, 2007; Wandersee, 1986; Wyner & Doherty, 2019; Balding & Williams, 2016; Hoekstra, 2000; Wandersee & Schussler, 1999; Wandersee & Schussler, 2001).

Limitations

The limitations of our study include potential overlap in subjects as we used the same listservs to collect data during factor analysis. This survey is a self-report measure and therefore is limited by the participants’ opinions of their own behavior. This research was only conducted with undergraduates in the United States in biology-related courses, and as such, the instrument will need to be re-validated if it is used outside the US, in a different language, or in another type of class (such as psychology courses).
Acknowledgments

We would like to acknowledge Dr. Jason Koontz for his assistance in collecting the data described in the pilot study of this paper. We would also like to acknowledge Dr. Elisabeth Schussler for serving as expert reviewer and supplying us with many helpful edits on previous versions of the PAD-I.
Appendices

Appendix A.

_Scree Plot Generated for EFA Round One Analysis Indicating a Six-factor Model_
Appendix B.

*Initial Scree Plot Generated for EFA Round Two Indicating a Seven-factor Model*
Appendix C.

*Second Scree Plot Generated for EFA Round Two after Removing Items 13, 14, 20, Indicating a Six-factor Model*
Appendix D.

Third Scree Plot after Removing Items 13, 14, and 20-22, Indicating a Six-factor Model
Appendix E.

Final Version of the PAD-I with Corresponding Factors

Caring for or Investment in Plants

1. I enjoy caring for house plants.

2. I enjoy caring for plants in an outdoor environment

3. I care about the plants that are in my neighborhood.

Necessity of Plants/ Importance of Plants

4. Plants are important because they help reduce the effects of climate change.

5. Plants are an important source of food for the world.

6. Plants are important to ecosystems.

7. Plants are important because they are a source of oxygen.

8. Plants are important because they are a source of new medicines.

9. Animals need plants in order to survive.

Plants Better than Animals (relative interest category)

10. I think plants are more useful to learn about than animals.

11. I think plants are more interesting to learn about than animals.

12. If I had to choose, I would rather keep houseplants than animal house pets.
13. When I go outdoors, I am more likely to notice the individual plants around me than any animals in the environment.

*Animals Better than Plants (relative interest category)*

14. Learning about animals interests me more than learning about plants.

15. Animal conservation is more interesting to me than plant conservation.

16. I think animals are more interesting than plants, in general.

*Positive Affect*

17. I enjoy going outdoors because of all the plants in the environment.

18. I would enjoy visiting a botanical garden.

19. I have a lot of good memories about plants.

20. Being around plants makes me feel happy.

21. In general, I think plants are very interesting organisms.

*General Attention*

22. I notice the crops that are grown near where I live.

23. When I take a walk outside, I notice the plants around me.

24. When I am in a wooded area I notice individual plants, not just the forest as a whole.

25. I notice all the plants in my environment, not just those that I eat.
References


Hershey, D. R. (2002). Plant blindness: "I have met the enemy and he is us". Plant Science Bulletin, 48(3), 78-84.


CHAPTER 3: POLLUTION WITHOUT PEOPLE: EVALUATING PLANT AWARENESS DISPARITY AND STUDENT PERCEPTIONS OF THE ROLE OF HUMANS IN PLANT-RELATED SOCIOscientific ISSUES

Introduction

As they develop biological knowledge, elementary children notice plants, make observations about them, and connect their importance to the surrounding ecosystem (Hatano & Inagaki, 1994). However, if this interest is not supported over time, children’s ability to notice plants, their assumptions about the importance of plants, and their interest in plants is typically low (Wandersee & Schussler, 1999). This diminished interest in plants is thought to be due to a culmination of factors including pre-college and undergraduate instruction focused on humans and other animals rather than on plants (Uno, 1994; ASPB, 2017). The term coined to describe this phenomenon was originally known as plant blindness (Wandersee & Schussler, 1999), but has since been changed to plant awareness disparity (Parsley, 2020).

Plant awareness disparity (PAD) is the tendency not to notice plants within the environment which can lead to the point of view that plants are not important (Parsley, 2020; Wandersee & Schussler, 1999). This does not mean that people are incapable of seeing plants, but rather they group plants together into a green background instead of noticing plants as individual biological units. This results in naïve and anthropocentric views such as plants are not important to people, plants are boring, or plants are not important research subjects (Hershey, 1993; Wandersee & Schussler 1999).
Students who are not plant aware often do not understand plants’ role in many important global issues. This has economic, political, and cultural ramifications, such as climate change, deforestation, genetically modified organisms (GMOs), sustainable agriculture, food security, biofuels, and plant conservation. For example, PAD contributes to a lack of general knowledge about how illegal wildlife trade affects plants and their conservation, leading to a lack of protections for plants (Margulies et al., 2019). Recently, Krishnan et al. (2019) called for more food and agriculture related efforts to stem PAD due to ever-increasing urbanization. Amprazis and Papadopoulou (2018) also called for better coverage of plants in primary school curriculum to highlight their importance to human welfare and biodiversity.

Socioscientific issue-based learning is a way to consider the role of plants in global issues. Embedding socioscientific issues (SSIs) within the classroom provides students with a way to consider components of societal issues and scientific problems that underlie these issues (Sadler, 2004). Without the ability to understand this interrelationship of society and science that define SSIs, or the opportunity to engage in evidence-based discussions about how plants are important to our everyday lives, students will not be prepared to meet the fundamental requirements of a scientifically literate populace (AAAS, 1993). Additionally, students who do not understand plants’ role in these issues are also likely to be botanically illiterate to a greater degree than students who do see the important role of plants.

Botanical literacy is defined as a subset of biological literacy which is affected by students’ lack of interest in plants, thus it is integrally related to PAD (Uno, 2009). Both Uno (2009) and Hershey (1996) identify PAD (and, more specifically, lack of interest in
plants) to be a major reason for the lack of botanical literacy observed in educational settings. This lack of interest in, and attention toward, plants often leads to a lack of understanding of why they are important to the biosphere and human affairs (Uno, 2009). Although the two are inextricably connected, PAD is considered to be separate from botanical literacy because students can have general knowledge about plants without recognizing their importance. The appreciation of plants’ importance in human affairs is the specific piece of knowledge that can lead to decreased PAD, which then often leads to increased general botanical literacy.

To conceptually understand how students build botanical literacy, we first developed a conceptual framework to integrate the aspects of PAD, botanical literacy, and socioscientific issues. The new framework is referred to as Functional Botanical Literacy. To explore aspects of this framework further, we used a causal map assignment to explore undergraduate students’ knowledge of the interrelationships between plants and the environment, and interviews to elucidate aspects of PAD that students exhibit and their understanding about the role of humans in relationships with plants and the environment. We used the number and nature of human links in a student’s causal map as a way to identify student reasoning about SSIs. Because SSIs include components of both societal and scientific problems (Sadler, 2004), we used students’ abilities to consider humans (the society aspect) within an environment (the scientific aspect). In this exploratory study, we asked students to create their own causal maps for the role plants played in a simulated environment that included a farm, river, production plant, and town. We evaluated the maps for students’ causal connection between items such as pollution, global warming, energy and food production, humans, and plant life. We
hypothesized that demonstrating the ability to link humans to plant-related SSIs in a causal map would serve as a useful intermediary between students having a complete lack of functional botanical literacy and having some functional botanical literacy abilities. Here we focus on the PAD and socioscientific aspects of the conceptual framework described below. Ongoing studies will continue to explore other parts of this framework. The aim of this study was to understand what aspects of PAD students exhibit when speaking about plants, how PAD correlates with components of student-created causal maps, and how students think about humans in the context of ecosystems.

To this end, we asked the following research questions:

1. What aspects of PAD do students exhibit when they talk about plants?
2. To what extent does a students’ level of PAD correlate with the factors they choose to include in causal maps of ecosystems?
3. In what ways do students consider the role of society, specifically of humans, within ecosystems?

**Background Literature**

**Plant Awareness Disparity (PAD)**

Plant awareness disparity (PAD) is proposed to have four components: attention, attitude, knowledge, and relative interest (Parsley, 2020; Wandersee & Schussler, 1999). Attention is tied to the classical definition of PAD and refers to how much attention students pay to plants in general. Attitude is how students feel about plants, particularly in situations where they are asked to learn about plants. Knowledge refers to how well
students understand the importance of plants. Relative interest indicates how interesting students find plants compared to other organisms, namely animals.

Many interventions have been proposed to address PAD and increase botanical literacy in K-12 classrooms, as well as university learning environments (e.g., Fančovičová and Prokop, 2011; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, and Guzman 2006; Ward, Clarke, and Horton, 2014). Some examples include a research-centered botanical curriculum (Ward, Clarke, and Horton, 2014) and an outdoor education program with hands on opportunities to interact with plants (Fančovičová and Prokop, 2011). Children who have rich experiences outdoors tend to have more knowledge about both plants and animals (Patrick & Tunnicliffe, 2011; Wyner & Doherty, 2019). However, noticing plants occurs more often when they are in the foreground (such as in botanical gardens) rather than in environments where animals are the focus (such as in a science center exhibit; Nyberg et al., 2019). Various authors have suggested ways to increase student interest in learning about plants such as by intentionally anthropomorphizing plants and using showy and decorative plant species, stimulant herbal drugs, and medicinal plants as examples (Balding and Williams, 2016; Lindemann-Mathies, 2005; Pany, 2014; Pany et al., 2019).

Wandersee, Clary, and Guzman (2006) probed students’ botanical sense of place to help them see and understand how plants are important to not only the human race, but also to the students. They found that by doing this, students returned to their youthful wonder and enjoyment of certain plants, their motivation to learn plant biology increased, and their past positive feelings towards chosen plants were reactivated, which then sparked botanical awareness and appreciation. Students even spontaneously shared plant-
related personal stories which in turn bonded the entire class into a plant-centered learning community (Wandersee, Clary, & Guzman, 2006).

Similarly, having a plant mentor has also been shown to result in lowered PAD in students (Wandersee & Schussler, 2001). Teachers can capitalize on students’ interests by sharing specialist knowledge, enthusiasm, and their own interest in plants (Strgar, 2007; Wandersee, 1986). To this end, Wandersee and Schussler took an activist approach in their 1999 paper, in which they announced that they were launching a campaign to “prevent PAD” which was followed up with special posters to hang in classrooms and even a children’s book about a plant.

Despite these many suggested solutions to PAD, there still does not exist a way to address PAD that brings in the natural interest of students while also clarifying the reasons that plants are relevant to students’ everyday lives. Our research contributes a new way to approach the problem of PAD that incorporates topics which are likely to interest students.

**Botanical Literacy**

Uno (2009) proposed and defined botanical literacy as a subset of biological literacy, and posited that botanical illiteracy exists because students lack interest in plants, have infrequent exposure to plant science before they reach the university level, and that while students are technologically advanced, they lack intellectual curiosity and rigor. This is currently the only known definition of botanical literacy, which is why more research (and perhaps a more clarified definition) in the area is crucial.
Uno (2009) suggested that the teaching of specific botanical content is not the main concern for combating botanical literacy, and that instead botany educators should promote understanding of major concepts, use more interactive and interesting teaching methods, and emphasize critical thinking and process skills. However, he also admitted that students do not find plants and botany inherently interesting, and that PAD has a powerful effect on how students view and think about plants. In a previous publication, Uno (1994) also noted that strict adherence to federal and state educational guidelines in K-12 classrooms often leads to plants not being taught well. He noted that plants are often not used to model over-arching biological concepts and that suggested botanical learning activities are often boring for students. There appears to be a disconnect between the definition of botanical literacy and the nature of botanical content, in that students who are not predisposed toward interest in plants are also less likely to learn about them.

Based on this, botany educators should try to strike a balance between finding plant-related topics that are of interest to students, while using engaging teaching methods that promote critical thinking and process skills at the same time.

Many approaches have been taken to combat these issues, such as designing an app for students to use for floral geo-location, integrating research experience into a botanical curriculum, having students use an app to photograph examples of plant families outdoors, and allowing students to use smartphones in botany laboratories to photograph specimens (Harper et al., 2015; Hartman et al., 2019; Pettit et al., 2014; Ward et al., 2014). However, these approaches are not equally accessible to all schools and universities wishing to use them. It is clear that botany educators need tools that can be
applied in the classroom without the requirement of outside resources that may not be available to them.

**Socioscientific Issues**

Socioscientific issues (SSIs) involve the use of scientific topics to engage in discussion and debate which can be controversial and requires some effort of moral reasoning (Zeidler & Nichols, 2009). Using SSIs for science learning contextualizes school science and provides a natural opportunity to engage in causal reasoning, as students are able to use their science understandings to grapple with real issues that intersect with their lives and connect to their communities (Sadler, 2004). Research related to the use of SSIs in classrooms has yielded evidence of the positive impacts of framing science instruction with issues on student learning of science concepts (Karahan & Roehrig, 2017). SSI-based teaching has also been shown to promote student interest in learning because the focus of learning is relatable, relevant, and important beyond the classroom (Stuckey et al., 2013). Within the undergraduate classroom, SSIs have been used to help students think about hydrological issues, distinguish between informal and formal decision-making, and as a foundation of a multidisciplinary science course focused on making decisions within scientific contexts (Dauer and Forbes, 2016; Dauer, Lute, & Straka, 2017; Sabel et al., 2017).

SSIs may be a useful way to motivate students to think about plants, as students typically do not consider plants within this context. When SSIs are used in instruction, students apply scientific knowledge, and they also may apply other types of information such as personal values. For example, when students across grade levels consider
medicinal plants and herbal drugs within an SSI context, they are more interested in plants and what plants can do for humans (Pany, 2014). We hypothesize that the use of SSIs in botany education can not only counteract PAD, but also help students learn more about plants. Plant-related SSIs may spark the interests of students because they will recognize some of these topics from their everyday life and begin to make connections as to how and why plants matter to humans.

**Conceptual Framework**

*Figure 1. Elements of Functional Botanical Literacy. Functional botanical literacy (FBL) is comprised of two main components: functional scientific literacy and botanical literacy. These two components merge together to become FBL. FSL is comprised of a combination of decision-making skills and socioscientific issues (SSIs). Within FBL,*
botanical literacy is combined with botanical SSIs which is reflected by the plus sign between the two components. The use of botanical literacy in combination with botanical SSIs is what sets FBL apart from FSL.

**Functional Scientific Literacy**

Functional scientific literacy (FSL) is a competent form of scientific literacy demonstrated by students, meaning that it is an intermediate level of literacy between mastery and non-mastery (Laugksch, 2000). An intermediate form of mastery like functional scientific literacy is appropriate for undergraduate students, as they are not yet expected to be masters in scientific literacy, but they are expected to be above the beginner level and continuing to develop this literacy. Intermediate forms of science literacy typically require students to perform a specific function to demonstrate their literacy (Laugksch, 2000; Zeidler et al., 2005). In the case of FSL, the functional goal is to make sound, scientifically-informed decisions about socioscientific issues (SSIs). SSIs are a fundamental dimension of scientific literacy, and decision-making about an SSI is a common functional goal across many forms of science literacy (e.g. Alred & Dauer, 2020; Dauer et al., 2017; Roberts & Bybee, 2014; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019).

**Botanical Literacy**

Botanical literacy is defined as what students should know about plants, and is a subset of biological literacy (and, by extension, a subset of scientific literacy) (Uno, 2009). Previous research states that botanical illiteracy exists mainly due to a lack of student interest in plants, low exposure to plants throughout school years, and because
students lack intellectual curiosity and rigor despite being technologically advanced (Uno, 2009). This characterization of botanical literacy is currently the only known definition of the term, making further investigation and description critical. Uno (2009) suggests that simply teaching botanical content is not the most effective way to combat botanical illiteracy. Instead, educators should prioritize using plants to teach major biological concepts, using engaging teaching methods, and utilizing plants to develop critical thinking skills. Unfortunately, students are not inherently interested in botanical content, and PAD has a powerful negative effect on the way students think and learn about plants (Parsley, 2020; Wandersee & Schussler, 1999; Uno, 2009).

Uno (1994) noted that teachers lack the flexibility they need to move beyond strict educational guidelines in K-12 environments, and this can contribute to botanical illiteracy. This is especially true if botanical examples are not used for over-arching biological concepts. Unfortunately, plants tend to be taught separately and in a way that does not engage student interest (Uno, 1994). The disconnect between the nature of botanical literacy and the teaching of botanical content itself is only contributing to the disparity among students who are and are not interested in plants, thereby contributing to PAD (Uno, 2009). Students who are naturally interested in plants will continue to seek them out, while those who are not will continue to avoid them at all costs (Uno, 2009). In order to mitigate this problem, educators need to find ways to engage all students’ interest in plants and use their interest as a segue into teaching botanical content that is useful and relevant to students’ lives (Uno, 2009). One potential way to do this is through the use of botanical SSIs, a hallmark of FBL.
Functional Botanical Literacy

Functional botanical literacy (FBL) is defined as the ability to make sound, scientifically-informed decisions about botanical socioscientific issues (SSIs). It is comprised of two main concepts: functional scientific literacy (FSL) and botanical literacy. FSL is defined as the ability to make sound, scientifically-informed decisions about SSIs (Laugksch, 2000). In the case of functional botanical literacy (FBL), the function that students will perform is making a decision about a botanical socioscientific issue (SSI). This specific decision-making exercise in a socioscientific context such as biofuels is also important because the botanical SSI students will make a decision about is designed to increase their interest in, and improve their attitudes toward, plants (Chapter 3; Parsley et al., In review).

Overall, functional scientific literacy is incredibly important to FBL because it forms the theoretical and functional basis for the skills students need to be considered functionally botanically literate. Because it is concerned with decision-making in the context of SSIs, FSL is comprised of both SSIs and decision-making skills. The other main component of FBL, botanical literacy, is simply defined as what students should know about plants (Uno, 2009). In this framework, we have combined botanical SSIs and botanical literacy because the combination of botanical SSIs and botanical literacy is what sets FBL apart from FSL.

Given that FSL shares many similarities with FBL, it is important to delineate between these two concepts. FBL differs from FSL in that 1) it specifically utilizes botanical SSIs only, and 2) it incorporates botanical literacy, and thus, is only appropriate
to be used in situations where efforts are being made to improve, measure, or assess botanical education in some way. While it may also be of use in other botanical education and literacy contexts, we designed FBL primarily to address plant awareness disparity (PAD).

The development of FBL to address PAD stems from a hypothesis that the botanical SSIs in FBL could appeal to student interest in and attitudes toward plants, potentially laying the groundwork for addressing PAD from a different starting point. PAD is made up of four components: attention, attitude, knowledge, and relative interest (Parsley, 2020; Wandersee & Schussler, 1999). Attention is the idea that students do not notice plants in their environment, and this component forms the basis for the original definition of PAD. Attitude refers to the phenomenon wherein students do not like plants, and do not enjoy learning about them. Knowledge is made up of students’ understanding (or lack thereof) about plants, particularly knowledge of the importance of plants. Relative interest refers to the fact that students tend to demonstrate more interest in animals than they do in plants. Previous interventions for PAD tend to target or measure the attention and knowledge components over the attitude and relative interest components (e.g., Fancovicova & Prokop, 2011; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman 2006; Ward, Clarke, & Horton, 2014). However, FBL is unique in that it is hypothesized to target student interest and attitudes through the use of botanical SSIs.

However, it is important to note that FBL could be used in other botanical education contexts beyond PAD. While this is certainly a possibility for future studies, the use of FBL in other contexts is beyond the scope of this work, as we are currently
primarily concerned with the development and characterization of FBL. It is also important to note that while FBL was designed to address PAD, this work is prioritizing the development and characterization of FBL rather than exploring potential relationships between FBL and PAD. The reasoning for this is that, while we know what PAD is and how it is characterized, we do not have this information for FBL. Therefore, it is important to lay the theoretical groundwork for FBL before exploring how FBL may affect PAD (and vice versa).

Despite the research conducted and the development of engaging ideas about how to improve botany education, researchers and educators still need a way to help students understand plants’ relevance to everyday life and their importance to humans. Our research contributes a potential solution to this problem with the development of FBL. In this paper, we will explore whether students connect humans and plants to botanical SSIs on their own within a botany course. This will allow us to understand whether students require specific instruction on how to improve their FBL or if they already demonstrate some of the skills related to FBL.

**Methods**

**Context and Participants**

Our study took place over two trimesters and included all students in an undergraduate botany course at a small Midwestern college (see Table 1 for demographic information). Thirty-eight students (100%) consented to participate in the first trimester and 40 students (100%) consented to participate in the second. The course consisted of primarily junior-level (3rd year) undergraduate students, was required for all biology
majors. While the course was introductory in skill level and largely lecture-based, the professor also used a mixture of class discussion, the Socratic Method, PowerPoints for students to add information to, worksheets, exposure to primary literature that also involved group activities, and debates that required preparation outside of the classroom.

The topics covered included plant anatomy, morphology, physiology, and diversity. Basic ecology was a programmatic (departmental) mandate that was woven throughout the course. The course also required concurrent enrollment in a weekly, two-hour long botany lab, which constituted 20% of the overall grade in the course and included three lab quizzes and an inquiry-based research project. The lab content closely followed the topics covered in class. The research project lasted the entire trimester.

Students chose a common garden plant with short germination time (e.g., radish, broccoli, turnip, tomato, white clover, lettuce) and designed and conducted a controlled experiment testing an ecological issue (e.g., amount of water, intensity of light, amount of fertilizer, kind of fertilizer, exposure to UV light, exposure to acid rain, etc.).
<table>
<thead>
<tr>
<th>Trimester</th>
<th>Gender</th>
<th>Ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Female</td>
<td>26 Asian/Asian American</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>10 Native Hawaiian, or Other Pacific Islander</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hispanic, Latino, or Spanish origin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>White</td>
</tr>
<tr>
<td>2</td>
<td>Agender</td>
<td>1 Another race/not listed</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>30 Asian/Asian American</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>8 Black/ African American</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hispanic, Latino, or Spanish origin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>White</td>
</tr>
</tbody>
</table>

Note: Genders or ethnicities are not included in the list if no one identified in that category.
Data Collection

**Plant Awareness Disparity Index**

Plant Awareness Disparity Index (PAD-I) is a 4-point Likert-style survey designed to determine the extent to which students exhibit PAD ideas as defined from the PAD literature (See Appendix A). The four aspects of PAD include attitude, attention, relative interest, and knowledge and were tested using topics like personal experiences with plants, interest in plants, and perceived knowledge of plants. We designed questions to address these ideas specifically and this resulted in a 28-statement instrument that was the first version of the Plant Awareness Disparity Index (PAD-I; Chapter 2). These questions also align with previous themes in the literature, such as having a plant mentor (Wandersee & Schussler, 2001) and plant conservation (Balding & Williams, 2016). Early factor analysis indicated the statements for each of the four components aligned somewhat differently than expected. The statements did not organize into the original four components but rather six factors that aligned with those components. However, Cronbach’s alpha reliability analysis indicated the instrument PAD-I has an alpha of 0.85 and so is a reliable measure of PAD. For the purpose of this study, we are only using the instrument to measure the level of students’ PAD. The final version of the PAD-I has been validated and has six factors as well. These factors still align very well with the original four hypothesized components of PAD and the instrument is reliable with a final alpha of 0.88. (Parsley, 2020; Parsley et al., in review). Along with structural validity, the PAD-I also indicates a high level of face and construct validity (Parsley et al., in review).

*Causal maps*
Causal maps are a type of concept map where students make connections between concepts, but instead of writing a word to describe the relationship on the connection between concepts, students write a plus or minus sign to indicate whether the causal relationship is positive or negative (i.e., it is increased or decreased). The professor instructed students how to construct a causal map via a handout modified from a worksheet from the Institute of Play (See Appendix B) and gave them a picture of an environment (Figure 2). Students were instructed to create a causal map based on the picture of the environment and to focus on the relationship between plants and the environment. The prompt for the causal maps was, “What roles do plants play in the environment shown?” Students were also asked to write responses to two questions: “Explain how your causal map demonstrates the relationships of plants and the environment?” and “If someone, a non-scientist, asked you to explain how plants connect to everyday life or situations, how would you answer using your causal map?” While the prompt instructed students to consider the relationship between plants and the environment, the picture they were provided included a human and items that involve humans such as a car, road, farm, and factory. We did not specifically ask students to identify humans or human-caused items in the causal map because we wanted to examine the extent to which they would identify those aspects of the environment without a specific prompt.

In the first trimester, students were given instructions on what a causal map is and how they should make one. The course instructor discussed with the project team how the students struggled to see the picture as an entire environment and make connections across the environment. In the second trimester, to support students in seeing how all of
the pieces of the environment were connected, we included a short scaffold activity published by the Waters Foundation (2014). The scaffold included a definition of a system and various characteristics about systems that students could use to better understand how to model a system with their causal maps. After the scaffold was introduced, the students completed their causal maps in the same manner as the first trimester, with the same model environment picture.

![Figure 2](image.png)

*Figure 2. Picture of an environment students were asked to consider for development of their causal maps.*

**Interviews**

We completed interviews with five students each trimester, for a total of ten interviews. These were conducted after the first causal map assignments. Interview participants were selected based on having a range of scores on the surveys, so as to get at student ideas about plants from differing levels of PAD and botanical literacy. Interviews were conducted by the first author via Skype and typically lasted an hour. In the interviews, we asked participants about their plant mentors, the role of plants in an
ecosystem, what factors contribute to the way they think about plants, memories they have of plants from being a child, what their relationship with plants and nature is like now, and what they found to be boring about plants.

**Data Analysis**

All collected data were blinded before analysis with a random ID number. Students received the same ID number for each piece of data collected (causal maps, and interviews). All names used in the results section below are pseudonyms.

**PAD Index**

To evaluate students’ level of PAD, we calculated the total score they earned on the original version of the PAD-I. The highest possible overall score was 112 and the lowest possible score was 28. A high score on the PAD-I indicates that students agreed with many of the statements about plants, therefore making them more aware of plants than students who earned a low score. In other words, a high score on the PAD-I indicates high levels of appreciation for plants. We used these scores to perform correlation analysis with scores from each of the subsections of the causal map scoring during the first (pre) round of causal maps. We used the initial causal maps for this analysis so we could explore if students’ levels of PAD were related to how they created their causal maps. This was the first step in exploring the relationship between PAD and how humans are represented in causal maps, an important aspect within our conceptual framework. If students are good at articulating the relationship between humans and other parts of the ecosystem (especially plants) they are beginning to show signs of functional botanical literacy.
Causal maps

The maps were coded using a rubric developed specifically for this study, using an analytical framework developed previously that captured an ecological framework (Jordan et al., 2009) and a systems reasoning framework (Hokayem & Gotwals, 2016). We chose these frameworks and adapted them to our rubric specifically to take both an ecological and a systems approach to explore what students know about plants and consider the role of plants in the environment. The rubric included five scoring criteria: plant links, human links, ecosystem links, causal reasoning, and systems reasoning (See Appendix C). All of the criteria had a range of 0 to 3, with 0 being the lowest score and 3 being the highest.

When assessing the criterion plant links, we considered the presence or absence of plants in general as a part of the assessment, as well as the presence or absence of producer-consumer relationships and photosynthetic relationships involving plants. For human links, we focused on the extent to which humans were included in the causal map, and, if they were included, how humans were integrated into the map using multiple relationships. For ecosystem links, we focused on the extent to which students used both abiotic and biotic factors in their maps equally. For causal reasoning, we looked at if students included a causal relationship on every connection they indicated, and if so, how correct those relationships were. For systems reasoning, we evaluated the level of interconnectivity of the map (how many links students drew between objects), as well as a clear flow of ideas (following linked objects to the final object) and the presence of one or more causal loops. We completed multiple rounds of co-scoring and rubric revision on ten of the student responses (13% of total maps), until we reached an instrument that fully
captured the students’ responses and we obtained a high interrater reliability (86% agreement). We then scored an additional ten student responses reaching a total of 20 dual-coded causal maps (26% of total maps) and reached 100% agreement following discussion. We then completed the remaining scoring alone which consisted of 18 causal maps from trimester one, and 40 causal maps from trimester two. We performed correlation analysis as described above to determine the extent to which any of these rubric category scores correlated with PAD-I scores. Because only the human links score was significantly correlated (see results), we moved forward with only that category for this project.

**Human Links**

Any term for a type of human (e.g. farmer, person, mother, sibling, etc.), along with any human-related SSI component (e.g. agriculture, pollution, factories, etc.) were coded as human links. Students with a score of 0 included no mention of humans or anything that was clearly related to or caused by humans (i.e. pollution, climate change, agriculture, etc.). Students with a score of 1 included no direct mention of humans but did include a mention of clearly human-caused or human-related things (cars, vehicles, pollution, consumption of fossil fuels, agriculture, etc.). Students with a score of 2 included the word humans or a human-related component but had limited connections from the human or human-related component to other ideas in the map, or only included the human or human-related component in the central idea of the map. Students with a score of 3 included the word humans, and sometimes included humans as the central part of the map, but also connected them to multiple other aspects in the map, including human-caused ideas.
We performed frequency counts to determine how many participants received each score level and paired the student scores between pre- and post-testing to evaluate whether students’ use of human links increased, decreased, or stayed the same (Figure 3). We then performed a one-way repeated measures ANOVA to determine the effect of time on student human links scores, and if students’ human links scores increased significantly at the end of the course.

**Figure 3.** Number of causal maps assigned to each human links score category.

**Interviews**

To answer research question 1, we qualitatively analyzed the student interviews using classical content analysis (Miles, et al., 2014) for the presence of the four components of PAD: attention, attitude, knowledge, and relative interest. We found that students spoke both positively and negatively about plants in the interviews, but for this
study, we focused on the negative (plant-unaware) behavior in order to answer our research question. When a student spoke about not noticing plants in their environment, we coded this as attention. When a student spoke about not liking plants or enjoying them, we coded this as attitude. When a student spoke about their current or past lack of knowledge about plants, we coded this as knowledge. Finally, when a student spoke about not finding plants interesting, or finding them less interesting than animals or other organisms, we coded this as relative interest.

To answer research question 3, we qualitatively analyzed the ten interviews conducted across both trimesters using descriptive coding (Miles et al., 2014). We looked for any mention of humans in the interview transcripts and labelled these as human links. As with the causal maps above, any term for a type of human (e.g. farmer, person, mother, sibling, etc.), along with any human-related SSI component (e.g. agriculture, pollution, factories, etc.) were coded as human links. We then analyzed only the human links quotations and used pattern coding (Miles et al., 2014) to find different types of human links. There were originally 20 different categories of human links, which we condensed down to 12 after considering overlap across the categories.

Results

Student Discussion of PAD Components

In research question 1, we asked, “What aspects of PAD do students exhibit when they talk about plants?” To answer this, we coded the interviews for the four components of PAD and conducted frequency counts to determine the number of times the four aspects of PAD were present (Table 2). We found a total of 104 quotes that indicated
levels of PAD across the four categories. The number of each student’s PAD responses ranged from three to twenty. We also performed frequency counts within each component of PAD and the number of responses within each category ranged from 20 to 34. Below, we report some examples of each category and how students responded to the interview questions.
Table 2.

*Frequencies of Plant Awareness Disparity Components*

<table>
<thead>
<tr>
<th>Name</th>
<th>Sarah</th>
<th>Molly</th>
<th>Samantha</th>
<th>Nick</th>
<th>Ashley</th>
<th>Tiffany</th>
<th>Whitney</th>
<th>Brendon</th>
<th>Maya</th>
<th>Brenda</th>
<th>Total Number of PAD Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attention</strong></td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td><strong>Attitude</strong></td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td><strong>Knowledge</strong></td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td><strong>Relative Interest</strong></td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total Number of Comments</strong></td>
<td>9</td>
<td>6</td>
<td>20</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>6</td>
<td>16</td>
<td>19</td>
<td>12</td>
<td>104</td>
</tr>
</tbody>
</table>
Knowledge

This was the most frequent component present in the interviews occurring 34/104 times. Students discussed having very little knowledge of plants before the course began, but also discussed how they were unwilling to seek out knowledge of plants on their own. For example, when Brendan was asked how he might improve his knowledge of plants he replied:

I’ve seen some of those like field guides where they'll be like a more academic thing like that… I would not want to have to grapple with that. Even maybe reading something like a book about plants and nature just seems not like my niche (Brendon, Trimester 2).

Brendon articulated that he would not pursue further knowledge about plants outside of the course because it was not something of interest to him. This was a typical response within the interviews, that students were unlikely to seek out plant knowledge on their own.

Students also articulated that they had not had a chance to learn about plants prior to the botany course. For example, when Maya responded about her prior opportunities to learn about plants she said, “I definitely disagree strongly about the fact that when I was younger, someone actively taught me about plants. I grew a lima bean at six…And I had one professor in high school who had ferns everywhere. That was it,” (Maya, Trimester 2). As Maya stated, and other interviews highlighted, students had little prior information about plants within their prior former schooling and/or that any prior information they did have, did not impact their understanding of plant life in any influential way. This
highlights the importance of plant mentors while also explaining why many students lack the knowledge of plants they need to become less plant blind.

Maya also spoke about a current lack of access in to learning about plants beyond her botany course stating: “I've taken a million and three human anatomy and zoology classes” while this botany course was her only exposure to plants knowledge during her undergraduate course work. However, Maya also stated that considering how much knowledge she has about human anatomy versus plants is not something she “really thinks about” (Maya, Trimester 2). Maya’s remarks also reinforce the finding that if students do not receive training about plants in formal coursework, it is unlikely they will seek it out elsewhere.

Finally, Brenda also supported this point in explaining about even when she was outside with family she did not focus on plant life, yet also points out how important a plant mentor may have been in helping her developing this knowledge stating “Yeah, I mean…we used to go fishing…it was more about like "Look how pretty it was." It was never like, "Oh, look at the silver maple…” It was just like, "Oh, look at the trees."…I never looked at the ground, (Brenda, Trimester 2). Brenda reflected upon the fact that despite being outside and around plants, she did not notice them, nor did she seek out this information. However, Brenda’s comment does highlight that if a plant mentor had pointed this out to her, she may have noticed more about plant life outside of formal schooling.
Attention

Attention and relative interest were the second most common themes in the data, representing 25 quotes out of 104. Most of the attention quotes identified reinforced previous findings that even though students from this class were in a rural area and were around plants often, the plants were treated as a backdrop and largely ignored. For example, when Molly asked what parts of the PAD-I she most related to, she stated, “I also agree with plants blend into the background in the outdoors. Just generally when you're around in a forest you don't really notice individual plants, you notice kinda them as a whole,” (Molly, Trimester 1). Molly cites a specific impact of PAD: an inability to notice plants as individual biological units, and instead seeing them as a green backdrop. This is a classic indicator of being unaware of plants.

When asked what would help her to gain a higher score on the PAD-I (in other words, decrease her PAD), Tiffany answered,

I think just being around them… I think things that make me appreciate plants more is like when… say there's a green space…and then it's wiped out and all the trees are cut down, and there's concrete put there…I really didn't appreciate it when it was there. I didn't realize how much of an impact it made until it's gone, (Tiffany, Trimester 2).

Tiffany readily admitted that she did not notice plants in her environment and cited the importance of appreciating their presence before they disappear. This is an important finding because, not only does it mirror prior literature, but it also demonstrates
that if plants disappear from an environment the observer is left with a sudden realization of what has been lost.

**Relative Interest**

Relative interest and attention represented the second most popular theme in the data, with a count of 25 out of 104 quotes. As usual, when asked about interests, students spoke about how plants and animals compared in this aspect and they preferred animals. The reason for why animals were more interesting were varied, however.

For example, when asked what questions on the PAD-I she disagreed with, Samantha said, “I enjoy learning about plants. Not really. Not good at it. I'm more interested in finding out about animals,” (Samantha, Trimester 1). Samantha’s statement indicates a very popular opinion among these biology students: one is either a plant person or an animal person, and Samantha does not identify as a plant person. She seems to believe that this is more than enough to explain her differences in interest, due to her lack of further explanation.

When asked what specifically she found to be boring about plants, Ashley answered, “I think the most boring part so far is trying to memorize all of the new terminology…that I've never seen before…I think that's the most boring, time consuming part of it,” (Ashley, Trimester 1). Ashley spoke about the terminology and vocabulary of botany being a challenging hurdle to overcome, and how she found these very uninteresting. This seems to be a common theme among biology students, and terminology has been shown to act as a barrier to learning not only botany but biology in general (Wandersee, 1988).
When asked the same question, Brendon answered, “I guess they're not mobile. I can't interact with a plant and it per se interact back with me. I can go for a run with my dog, or things like that,” (Brendon, Trimester 2). When asked why plants’ lack of mobility was an issue for him, he responded, “I guess it's just biomechanics is an interest of mine. How do animals move, how do they do the things they do?... Things like that are just of interest to me,” (Brendon, Trimester 2). Brendon echoes the sentiments of several other findings in botany education, as one of the chief complaints against plants is that they do not, “do anything.”

Overall, the interview analysis found that these students clearly preferred learning about animals to learning about plants and cited the difficult terminology and their interests in animals due to their ability to move and the biomechanics behind this ability.

**Attitude**

Attitude was the least common component of PAD in the interviews, occurring in only 20 out of 104 total responses. When students spoke about poor attitudes regarding plants, they usually either echoed reasons for why plants do not interest them (indicating a potential link between interest and attitude), or they spoke about bad memories regarding plants.

For example, when asked, “Is there any specific memories that you can think of that stick out in your mind that you can describe for me, regarding plants?” Sarah answered,

Yes. In my goat’s pasture, there were these huge weeds that were so…they were super rough and had a tubular stem. It would pollinate leaves that were
prickly…We'd have to pluck them. But…their roots were fairly deep…they'd just
dent because they were like a tube…,(Sarah, Trimester 1).

Sarah’s answer emphasizes the fact that students need positive plant experiences early in life. The fact that Sarah continued to remember such a negative experience and continued to have a poor attitude regarding plants because of it demonstrates that negative plant experiences can continue to have an impact long after they happen. Having a plant mentor can explain these negative experiences and put them into the context of why plants operate the way they do (for example, explaining why the plant had prickly leaves to deter herbivory) may help alleviate this issue.

When asked why she thought she scored low on the PAD-I, Whitney responded, “I'm not really a plant person. I don't really think too much in regard to plant life. It never really interested me, so I think that's why I scored on the lower end,” (Whitney, Trimester 2). Whitney demonstrates a classic case of attitude-related PAD as she is rather vague in her reasoning and simply states that she does not like plants. This echoes Samantha’s sentiment of not being interested in plants because she just is not a “plant person,” which is what leads us to believe that the components of attitude and interest are related somehow.

**Correlation Between PAD and Human Links**

In research question 2, we asked, “To what extent does students’ level of PAD correlate with the factors they choose to include in causal maps of ecosystems?” To answer this, we conducted a correlation analysis between the pre-test scores on the PAD-I and the five criteria we used to analyze the causal maps (plant links, human links,
ecosystem links, causal reasoning, and systems reasoning). This allowed us to explore the initial connections between students’ PAD levels and their ideas demonstrated in the causal maps. We found that the PAD-I score was only significantly correlated with one causal map criterion: human links (R= 0.376, p= 0.024) (Table 3). This indicated that perhaps student PAD scores and how students represented the links between plants and humans in their causal maps were somehow related. Despite having a high standard deviation, the result that indicated PAD and human links might be related was unique and led us to explore the human links components of the causal maps in more detail and compared them with indications of PAD in the interviews.

Table 3.

Results of PAD-I and Trimester One Pre-test Causal Map Criteria Correlation Analysis

<table>
<thead>
<tr>
<th>Causal Map Criteria</th>
<th>R</th>
<th>p</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Links</td>
<td>-0.128</td>
<td>0.455</td>
<td>1.167</td>
<td>1.231</td>
</tr>
<tr>
<td>Human Links</td>
<td>0.376*</td>
<td>0.024</td>
<td>1.250</td>
<td>0.806</td>
</tr>
<tr>
<td>Ecosystem Links</td>
<td>0.086</td>
<td>0.620</td>
<td>1.278</td>
<td>0.701</td>
</tr>
<tr>
<td>Causal Thinking</td>
<td>-0.109</td>
<td>0.528</td>
<td>1.306</td>
<td>0.668</td>
</tr>
<tr>
<td>Systems thinking</td>
<td>-0.109</td>
<td>0.527</td>
<td>0.972</td>
<td>0.696</td>
</tr>
</tbody>
</table>
Student Inclusion of Human Links in Causal Maps

In research question 3 we asked, “In what ways do students consider the role of society, specifically of humans, within ecosystems?” To answer this, we conducted frequency counts to determine how many students increased their score for use of human links in their causal maps. We then evaluated the number of students in each trimester who increased, decreased, and maintained their scores from pre- to post-causal map evaluation. In trimester one we found 11 increased their score, ten decreased their score, and 15 maintained their score while two did not do the post-test causal map. In trimester two we found that 14 increased their score, 11 decreased their score, and 15 maintained their score. In trimester one, we did not see a significant increase in mean human links scores from pre (M= 1.25) to post-test (M= 1.28) (Wilks’ Lambda = 0.999, F (1,35) = 0.036, p = 0.851). We also found no significant difference between pre (M= 1.525) and post-test (M= 1.625) in trimester two (Wilks’ Lambda = 0.990, F (1,39) = 0.394, p = 0.534).

To better demonstrate what each score level looks like, we chose 4 representative example causal maps (one from each score level) to be described in more detail below (see Figure 4) to demonstrate the distinguishing criteria used to score the causal maps.

Score of 0

In Figure 4A, the student did not refer to “humans,” or, “people,” and did not include any type of concept that is directly related to or caused by humans. Every other item on the map is something found in nature and not focused on humans in a socioscientific context.
**Score of 1**

In Figure 4B, the student included components such as, “factories,” “cars,” “pollution,” “agriculture,” and even, “jobs” which are all concepts relating to what humans do in an environment. However, this student did not actually use the word, “humans,” or, “people,” in their map either, despite the fact that many of the concepts included in the map are directly caused by humans in a socioscientific context.

**Score of 2**

In Figure 4C, the student included the word, “humans,” in their pre-test map, however, humans have only one connection to the rest of the map and are largely separated from all of the other elements appearing in the map. Additionally, the word, “humans,” is only connected to the word, “oxygen,” which is not a concept directly caused by humans in a socioscientific context.

**Score of 3**

In Figure 4D, the student included the word, “people,” but also included several connections between, “people,” and other elements of the map. There are seven total connections between the element, “people,” and other concepts in the map. Of those seven, three can be thought of as concepts directly caused by humans in a socioscientific context. “People” is connected to “cars,” “gas,” and “factory pollution,” all of which are related to human impacts on the environment. The other four elements connected to the term, “people,” are “oxygen,” “cows/livestock,” “energy production,” and “produces O₂ and CO₂ to help balance environment,” which is the central idea of the map. These
connections point to an understanding of how humans are dependent upon plants for oxygen, and how we have domesticated cows for agricultural use.

Figure 4. Examples of each level of causal map scoring. A. Score of 0. No mention of humans or any human-caused phenomena. (Participant 11, pre-test causal map). B. Score of 1. Human-caused phenomena (e.g. agriculture, pollution, wind energy) are mentioned, but humans are not. (Participant 8, post-test causal map). C. Score of 2. Humans are mentioned in the map but are isolated from the other ideas present. (Participant 40, pre-test causal map). D. Score of 3. Humans are present and so are human-caused phenomena.
(e.g. cars, gas, factory pollution) and humans are highly connected with the rest of the ideas on the map, as well as the human-caused phenomena. (Participant 12, pre-test causal map).

**How Students Think about PAD and Botanical Literacy**

To further explore research question 3, we examine interviews with students after they completed the first causal maps. Within interviews from all ten students, we identified 12 main categories of human links and found a total of 158 quotes related to the role of humans (Table 4). Individual student quotes related to the role of humans ranged from seven to 26. Due to the limited number of quotations for most of the categories, we will only discuss the top four here.

Table 4.

*Frequencies of human links codes found in interviews*

<table>
<thead>
<tr>
<th>Types of Human Links</th>
<th>Overall Frequency</th>
<th>Number of Students Who Mentioned Each Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familial human links</td>
<td>44</td>
<td>9</td>
</tr>
<tr>
<td>Plant Mentor</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>SSI human links</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Plants provide x for humans</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Experiences with peers</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>Instructor influence</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Plants affect our environment</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Humans are dependent upon plants</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Experiences with other professors</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Anthropocentric humans</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Plants do not interact with people</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>General human links</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
**Familial human links**

The most prolific type of human links was familial human links, meaning that most mentions of humans in the interviews had to do with the interviewees’ families. One example of this was when a student said, “One of my grandmas was really an avid gardener and I remember she would be gardening, and it may be something I remember from then was planting marigolds around your garden in that way your rabbits won't get to it.” (Sarah, Trimester 1).

Many of the familial human links codes were referring to childhood memories that the interviewee shared with a family member, usually a parent. Another example of this is when Samantha said, “I would say probably my mom would have been the most influential one. She has a garden so I wouldn't actively be interested but she would try and teach me and what not.” (Samantha, Trimester 1). Similarly, Nick said,

So, my mom, well, we have a garden at my house. So, I've learned some things through there, like taking care of plants, the needs of a plant. My mom has flowers everywhere, so always watering and things like that. When I say taught, it's kind of informal (Nick, Trimester 1).

Overall, this suggests that students thought of plants in terms of memories they had with family members interacting with plants, particularly in gardens. However, they had varying degrees of interest in learning from those family members or wanting to take part in those activities themselves.
Plant mentor

The second most prolific type of human link was a mention of a plant mentor. A plant mentor is any individual (though they are often a parent) that teaches a student about plants in a meaningful way. Because a plant mentor is also often a family member, there was a lot of overlap among the categories of plant mentor and familial human links. However, plant mentors are not always or exclusively family members, as some students brought up past teachers and scout masters as their plant mentors. In addition, a plant mentor is someone who takes a mentee under their wing with the purpose of teaching them more about plants. In this way, a family member may be a plant mentor, but a student simply remembering a family member as being interested in plants or in gardening does not necessarily mean that person was a plant mentor to the student. The interaction between mentors and mentees often results in fond memories of activities where the student was afforded the opportunity to learn about plants in a setting outside of academia, as well as reduced PAD. One example of a description of someone’s plant mentor was when an interviewee noted,

I would say possibly it could be two people. My mom is always actively trying to get me out. She's the one that's like, "I know you want to go walk on the conservation park," or something like that. Then one of the most influential in my life, I think it was my seventh-grade science teacher. I'm still really good friends with him now. He was one of the ones that was leading the group that I was talking about earlier, the outdoor group. That was probably the moment in my life where my interest in the environment and plants began. (Nick, Trimester 1).
Similarly, Ashley stated,

Oh yeah. My father. Most of my father's side of the family are farmers, they own farms. They plant corn, soybeans, things like that. In the Chicago area, we got the giant garden where we plant tomatoes, beans, bell peppers, all kinds of plants. My father and I and all my siblings would always plant a garden every year (Ashley, Trimester 1).

Tiffany also cited her father as a plant mentor.

So when we'd go on hikes in the woods, my dad would pick up a leaf and he would show it to us, and be like, "This is an oak leaf, and you can tell because of the structure, or the curve," you know, edges, or whatever, and then, "This is a maple, and you can see it's pointy," or like shagbark hickories, "Oh, you can see it's like shaggy," and just stuff like that. And not only about plants, but about other things. Like we'd see scat on a trail, and he'll be like, "Oh, this is from a coyote. You can tell because there's fur in it," like that kind of thing. (Tiffany, Trimester 2).

When students discussed the plant mentors who were family members, they went into detail beyond what they did when they spoke only of familial connections (see above). Plant mentors were those who encouraged them to look further and who actually influenced them to do so.
SSI-related human links

The third most prolific type of human links was SSI-related human links. Compared to the first two types of human links which made up 44 and 31 of the total 158 human links noted respectively, SSI-related human links only numbered 16 total human links. Therefore, much like the causal maps, some students were making some connections to SSIs, but those connections were rare. Human links were deemed SSI-related if they mentioned a human-caused or human-related phenomenon such as agriculture, climate change, or pollution. This trend was extended from the causal map analysis where I primarily focused on these SSIs in their causal maps as well.

An example of an SSI-related human link is when Samantha said,

So, I would say the cultivation of the different plant products leads to more of an economic system, like an agriculture that's more domesticated and then to farming, I would say that more relates to human interaction with it and how humans cultivate the food and the use of agriculture to make the different systems, the different ways of life. (Samantha, Trimester 1).

Tiffany cited plants as a carbon sink, saying,

I think plants are very important to the ecosystem because they provide food for other organisms. They prevent erosion. They help everything function the way it should. They provide shelter. They're necessary for foliage when they shed their leaves, you know, soil, and then they're carbon sinks, which we learned about. (Tiffany, Trimester 2).
Brendon cited plants as important for carbon filtration and nitrogen run off when he said,

I'd say they're pretty fairly important. Looking at a different forest like the amount of carbon they can hold or like the weeds and things. Plants are important for nitrogen run off, so there's like less... in our way of planting agriculture. Making sure there's not nitrogen run off into our water sources. I'd say they're pretty important to the ecosystem, because they're a part of those cycles, and they keep a lot of things in check. Obviously, they help us breathe like photosynthesis.

(Brendon, Trimester 2).

Students who mentioned plant-related SSIs such as carbon sinks and agriculture were already engaging in the beginning stages of functional botanical literacy, as they were able to elaborate on the connections between humans and plants in these contexts.

**What plants provide for humans**

The fourth most prolific type of human links were those that mentioned what plants provide for humans. Many of these links mentioned things like food, oxygen, and food for other animals, and these made up 15 of the 158 coded human links. This is demonstrated by Molly when she said,

I think, honestly, plants are crucial. They … produce oxygen, stuff like that for everyone to survive, everyone to breathe in, but they also start out off kind of the basis of the food chain. So, I mean basically what I eat has pretty recently consumed an animal that has already consumed plants or has consumed plants themselves. I even consume plants so just in generally speaking for nutrition, for
Molly also discussed plants and what they provide as her first interaction with plants,

Not that I'm really aware of besides just like probably when I was a kid we always had certain fruit trees, fruit brushes, stuff like that where I'd go out and eat them but that was really kind of the first interaction that I ever had really with plants. (Molly, Trimester 1).

In both examples, Molly thought of plants in the context of what they provided for her and other animals. While this is a valid consideration, it shows she may not have been thinking of plants as functioning beyond this limited role.

Sometimes students emphasized the importance of plants but were somewhat vague in how plants are important. For example, Tiffany said,

I feel like I understand that ecosystems, every part of them are essential for how they function. And if something's eliminated, then it's not going to work as well, or function as it should. So, plants are very necessary not only for ecosystem life, but also for resources for us. But I feel more strongly about their influence on the ecosystem and how it works because if that's gone, then we're not going to have resources. (Tiffany, Trimester 2).

Tiffany’s vagueness is evident in how she referenced ecosystems but did not specify what plants do for them or how plants affect them. Overall, this indicates that
students see the importance of plants for what humans require. Unfortunately, though, they often do not also see the importance of the role of humans in the same ecosystem.

**Discussion**

Previous work indicated that if students are taught about plants in the context of something that interests them, they will learn more (Pany, 2014). Our study builds upon this idea, though our use of SSIs is novel. The results of our interview analyses indicate that if students do not have previous positive experiences with and/or opportunities to build knowledge about plants they can easily develop a negative attitude toward them. Because not everyone has access to positive plant-related experiences or plant mentors, the implementation of SSIs in a botany course is an original way to approach plants from a perspective that will naturally interest students and highlight the importance of plants in everyday life, thereby helping them to understand why plants are worth learning about. Findings from this study begin to address current levels of understanding among undergraduate students so these issues can be addressed.

First, this study contributes a new conceptual framework called *functional botanical literacy* that has been useful in demonstrating the extent to which students are plant blind and botanically illiterate. This framework incorporates aspects of functional scientific literacy (Zeidler et al., 2005; Ryder, 2001), socioscientific issues (Sadler, 2004; Zeidler & Nichols, 2009), and botanical literacy (Uno, 1994; 2009). This framework is intended to be a new way to view the problem of PAD that places emphasis on developing science literacy skills (Roberts & Bybee, 2014; Laugksch, 2000) with the overarching goal that students will meet the requirements of a scientifically literate
populace (AAAS, 1993). Using this framework requires students to consider causal connections within the environment as they work their way through plant-related SSIs which is a valuable learning experience.

Second, findings from this study also begin to address the possibilities of causal maps as an instrument to discover students’ perception of, knowledge of, and attitudes toward, plants in order to affect change. Previous work has attempted to use a writing template to prompt students’ botanical sense of place to decrease PAD and increase botanical literacy (Wandersee et al., 2006). However, empirical research has not yet explored the possibility of also using causal maps to demonstrate botanical literacy. Causal maps have not been explored in the context of decreasing PAD and increasing botanical literacy, and our work explores this in detail.

We found that while scores on the PAD-I were positively correlated with the human links scores from the causal map evaluations, students do have limited ideas in general about the role of humans in plant-related SSIs. The positive correlation indicates some sort of relationship between PAD and human links scores; however, the interviews did not help us to understand what this link was, and further research in this area is needed. Students mostly talked about personal experiences with their families and plant mentors when asked about plants in the context of human links. Many times, the familial human links would overlap with plant mentor human links, as plant mentors are often family members that have taught the subject about plants. This aligns with the findings put forth by Wandersee and Schussler (2001) that having a plant mentor is very important to reduce PAD. However, we extend this finding by indicating that family members are often plant mentors, and that despite these relationships, students still struggle to place
humans in the context of plant-related SSIs and ecological systems. Students tend to separate personal experiences with plant mentors and family members from their consideration of how humans in general play a role in the environment where plants are concerned. This trend could point to another anthropocentric point of view that is skewed toward people (especially those the students know directly) being more important to student ideas about plants than ecological interactions are, which could have implications for how students relate to plants and the environment. Do they have to have a personal connection to an environment to care about it? Is a plant mentor or family member enough to connect a student to their environment? These are important considerations moving forward in this line of inquiry and could be valuable as future directions for further research.

Third, while students do struggle to place humans in the context of SSIs even with plant mentors and positive plant-related experiences, our study still indicates that it is very important to have a plant mentor and positive experiences because a lack of these opportunities leads to PAD behaviors. This finding aligns well with that of previous PAD literature that suggests the importance of plant mentors cannot be overestimated, and that childhood experiences with plants play a prevalent role in PAD during later years (Wandersee, Clary, & Guzman, 2006; Wandersee & Schussler, 2001). We also found that attitude and relative interest are related. If students do not find plants interesting, they are more likely to have a negative attitude toward plants. However, if students do not have early opportunities to learn about plants, it is unlikely they will have the chance to find out what is interesting about plants. This lack of knowledge and interest echoes from childhood into adulthood as our study found that students who lacked previous childhood
experiences and learning opportunities with plants still portrayed behaviors that indicated high PAD levels years later. This is a novel finding as previous studies have focused on one particular educational experience without the opportunity to look at students’ history with plants (Schussler & Olzak, 2008; Wandersee, 1986). However, more research is needed to determine how these behaviors change over time and whether they can be reversed later in college with further plant-related experiences.

Finally, we were not surprised that students did not significantly improve their causal map scores from pre to post, as other work has shown that one trimester is not enough time for students to increase their botanical literacy (Wandersee & Schussler, 1999). What did surprise us with the causal maps was that undergraduate students, advanced in their majors, still struggled with considering biological systems and how those systems related to human systems. The undergraduate students within this study struggled with mechanistic causality, in the same manner seen with younger learners (Hatano & Inagaki, 1994), as evidenced by the lack of progress in causal map construction. While the instructors’ pedagogy was based on active learning, our study found that students required additional scaffolding and teacher guidance to consider and make connections between humans in plant-related SSIs and ecosystems as a whole. Our study implies that students do not demonstrate these abilities on their own but require ongoing support throughout their course work.

In sum, our findings align with that of Wandersee (1986) in that motivation, attitude, and interest are factors that affect PAD and botanical literacy. PAD can be discovered by utilizing an aspect of plants (SSIs) that increases student interest. This study further supports the idea that perception systems have the greatest causal effects on
PAD as has been suggested in the past (Balas & Momsen, 2014; Schussler & Olzak, 2008; Patrick & Tunnicliffe, 2011). Additionally, we support the finding that students become more invested when their teachers are invested, as indicated by our finding regarding students being affected by their professor’s attitude toward plants (Strgar, 2007).

**Conclusions**

Our study further reinforces the importance of early positive plant-related experiences, especially with plant mentors. It offers a snapshot of how negative childhood experiences related to plants can echo into adulthood, furthering PAD-related behaviors in students. We also offer a new finding that interest in plants and attitudes toward them are related, as we found examples of students who did not like plants because they did not find them interesting and vice versa.

Using causal maps can allow instructors to see if students are understanding basic content, but also to see how they are engaging in higher level thinking and making connections as they progress through a course. However, this study also shows that instructors may need to more intentionally bring the roles humans play into conversations about ecosystems and environments. In this way, our study solidifies the finding that bringing plants to the attention of students can improve their PAD (Lindemann-Matthies, 2005; Fančovičová & Prokop, 2011). We found a connection between PAD and human links, but without this instruction from the professor and a more explicit conversation regarding how humans interact with the environment, it is difficult for students to articulate their ideas about these topics. While introducing students to the importance of
plants is crucial, helping students to see how their own actions affect other organisms is also critical. This is especially important as students tend to attribute life to being human, and so may assume that plants are lifeless unless shown otherwise, which has implications for students’ role in plant conservation and their decisions regarding such efforts (Yorek, Sahin, & Aydin, 2009; Balding & Williams, 2016).

Finally, the use of causal maps may be a valuable alternative way to allow students to demonstrate their knowledge and understanding of complex relationships. Importantly, though, if instructors are going to use causal maps in these ways, they will need to be intentional with how they structure the activity to make sure students have a clear understanding of how to create effective causal maps. Using these maps also requires no external resources such as research lab supplies, student-owned smartphones, or app access that less technologically-advanced classrooms may not have access to, which previous proposed solutions to PAD have assumed (Ward et al., 2014; Pettit et al., 2014; Harper et al., 2015).

Overall, this study highlights the importance of explicitly including the roles of humans in discussions of ecosystems and environments. Future planned work will expand this study to explore additional demographics and course contexts. In addition, we will continue to explore various ways in which instructors can address PAD and botanical literacy in undergraduate classrooms.

Limitations

This study is limited because of the small sample size, limited demographic diversity within the botany course, and limited time within the trimester to complete the
study and administer the causal maps. However, it has important implications for undergraduate biology instructors as they consider how to teach students about botany topics either in stand-alone botany courses, or as part of general biology or ecology courses. Further work should explore the use of causal maps to explore FBL in a greater diversity of courses and demographic backgrounds.

**Acknowledgments**

We would like to acknowledge the University of Memphis College of Arts and Sciences for funding the data collection associated with this paper.
Appendices

Appendix A.

Plant Awareness Disparity Instrument

Note: This version of the Plant Awareness Disparity Instrument is no longer in use, and has been changed since our study took place. The current version has been validated and submitted for publication to another journal.

Directions: Please indicate the extent to which you agree or disagree with the following statements.

1. I have many good memories about plants.

<table>
<thead>
<tr>
<th></th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
</tr>
</thead>
</table>

2. In general, I am very interested in plants.

<table>
<thead>
<tr>
<th></th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
</tr>
</thead>
</table>

3. I have taken or plan to take plant courses for my degree.

<table>
<thead>
<tr>
<th></th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
</tr>
</thead>
</table>

4. When I was younger, someone actively taught me about plants.
5. I enjoy gardening.

6. For this statement, please mark “Agree.”

7. I enjoy being outdoors so I can experience nature in an immersive way.

8. Plants are essential for medicine.

9. Life on earth could not exist without plants.

10. I enjoy caring for house plants.
11. I think plants are unimportant to humans.

Disagree  Somewhat disagree   Somewhat agree   Agree

12. Plants are necessary to make clothing.

Disagree  Somewhat disagree   Somewhat agree   Agree

13. Efforts to protect and conserve plants are important.

Disagree  Somewhat disagree   Somewhat agree   Agree

14. Plants can help improve climate change.

Disagree  Somewhat disagree   Somewhat agree   Agree

15. I think plants are boring.

Disagree  Somewhat disagree   Somewhat agree   Agree

16. Plants are an essential source of food for the world.
17. I am familiar with how food crops are grown.

Disagree  Somewhat disagree  Somewhat agree  Agree

18. Animals need plants to survive.

Disagree  Somewhat disagree  Somewhat agree  Agree

19. I would enjoy visiting a botanical garden.

Disagree  Somewhat disagree  Somewhat agree  Agree

20. I would like to read books about plants.

Disagree  Somewhat disagree  Somewhat agree  Agree

21. Being around plants makes me feel relaxed.

Disagree  Somewhat disagree  Somewhat agree  Agree

22. When I am in a wooded area, I notice individual plants.
23. I want to know the names of the plants I see outside.

Disagree  Somewhat disagree  Somewhat agree  Agree

24. Plants are important to ecosystems.

Disagree  Somewhat disagree  Somewhat agree  Agree

25. I can identify what part of a plant I am eating when I eat a vegetable.

Disagree  Somewhat disagree  Somewhat agree  Agree
Appendix B.

Causal Map Assignment

Creating a Causal Map

What are causal maps?

A causal map shows relationships between actions and effects within a defined system. A causal map is a way to physically express connections that exist within a system. A finished causal map shows relationships between elements in a system, if those relationships have a positive or negative effect on the relationship, if there are feedback loops to the system where one thing causes an effect, and that effect provides input to the system to respond in some way, and where they are placed in the system to eliminate, or modify a positive or negative effect.

To see a completed causal map, see page 3 of this hand-out that has a completed causal map about excessive hallway noise between classes.

For this activity, you will create a causal map of the picture of the environment included in this hand-out on page 4. The focus of your causal map is the relationship between plants and the environment.

What to do:

1. Looking at the environment picture in this hand-out, answer this question: “What roles do plants play in the environment shown?” Put your answer in the middle of a blank piece of paper.
2. List all factors that are involved in your answer around the center of the piece of paper. For example, factors may be things like “water” or “oxygen”. Leave space around the factors for additional writing. Don’t put circles around your ideas yet.

3. Draw arrows between related factors and how those factors relate to your answer in the middle of the page. Arrows can be in one direction (-->) or can be multidirectional (<-->).

4. Look for feedback loops. A feedback loop is a place where the cause becomes an effect and an effect becomes a cause. An example of a feedback loop from the causal map example is the cause (the number of kids sneaking on the elevator) affects the number of kids waiting for the elevator which causes an increase in the amount of hallway noise and this feedback continues as more kids sneak on the elevator which affects the number of kids waiting in the hallway for the elevator which continues to cause elevated hallway noise.

5. Use circles or a highlighter or a different colored pen/pencil to show the feedback loops in your causal map.

6. Add “+” and “-” on the arrows to show relationships between factors. A “+” indicates that the relationship is one in which something is added. A “-” indicates that the relationship is one in which something is removed.
After you have drawn your causal map, answer the following questions:

1. Explain how your causal map demonstrates the relationships of plants and the environment?

2. If someone, a non-scientist, asked you to explain how plants connects to everyday life or situations, how would you answer using your causal map?

Causal Map Example of Noise in the Hallway:
Causal Maps

Key Questions

- What relationships do you see in your causal map?

- Do you see any feedback loops in your causal map? (Remember to check yourself by making sure both factors affect each other.)

- What is a possible leverage point in your causal map?

---

**SAMPLE KEY QUESTION ANSWERS**

What relationships do you see in your causal map? We found relationships between number of students in the hall and hallway noise, student socialization and hallway noise, and teachers corralling and hallway noise.

Do you see any feedback loops in your causal map? Yes, the number of students waiting for the elevator increases the number of students sneaking on the elevator and that increases the number of students getting on the elevator. Then more students wait by the elevator to sneak onto it.

What is a possible leverage point in your causal map? If we improve the system for monitoring students on the elevator, fewer students will be waiting for the elevator (and trying to sneak onto it), so there will be fewer students waiting around in the hallway.

---

**HINT** Avoid including quantifiers in front of effects. For example, more, less, lack, etc.

---

1. Identify a problem and put it in the center of a piece of paper.
2. List all factors that are involved in the problem around the center of the piece of paper. Leave space.
3. Draw arrows between factors that seem related.
4. Ask the key questions whenever you think you have found a feedback loop.
5. Highlight any feedback loops that you find.
6. Add “+” and “−” to show relationships between factors.

---

www.instituteforplaying.org
Environment Picture to use for YOUR causal map:
Appendix C.

Causal Map Scoring Rubric

### Plant Links

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Includes plants and makes clear connections to the environment including components of BOTH photosynthesis AND producer/consumer relationships.</td>
</tr>
<tr>
<td>2</td>
<td>Includes plants and makes clear connections to the environment including components of EITHER photosynthesis OR producer/consumer relationships, but not both.</td>
</tr>
<tr>
<td>1</td>
<td>Includes factors that are related to plants (but not plants themselves), but still includes components of BOTH photosynthesis AND producer/consumer relationships</td>
</tr>
<tr>
<td>0</td>
<td>Includes factors that are related to plants (but not plants themselves) and either does not connect or connects to components of EITHER photosynthesis OR producer/consumer relationships, but not both.</td>
</tr>
</tbody>
</table>

Plants need to be the central theme in order to make a high score. Just “Plant photosynthesis, amount of plants,” do not qualify but simple “plants,” do.

### Human Links (adapted from Jordan et al., 2009)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Makes clear connection between humans and how they interact with the environment with multiple relationships</td>
</tr>
<tr>
<td>2</td>
<td>Includes humans, but has limited connections to central ideas</td>
</tr>
<tr>
<td>1</td>
<td>Includes factors that are caused by humans, but do not mention humans</td>
</tr>
<tr>
<td>0</td>
<td>Does not include humans at all</td>
</tr>
</tbody>
</table>
Farming and crops count as caused by humans.

**Ecosystem Links** (adapted from Jordan et al., 2009)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Contains approximately equal numbers of both abiotic and biotic factors with clear connections between both</td>
</tr>
<tr>
<td>2</td>
<td>Contains approximately equal numbers of both abiotic and biotic factors, but most connections are abiotic to abiotic or biotic to biotic</td>
</tr>
<tr>
<td>1</td>
<td>Contains significantly more abiotic or biotic factors with few connections between abiotic and biotic</td>
</tr>
<tr>
<td>0</td>
<td>Contains either abiotic or biotic factors, but not both</td>
</tr>
</tbody>
</table>

Food is biotic.

**Causal Reasoning**

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>All relationships have a clear and correct causal relationship indicated</td>
</tr>
<tr>
<td>2</td>
<td>Some, but not all, relationships have a clear and correct causal relationship indicated</td>
</tr>
<tr>
<td>1</td>
<td>Very few causal relationships are included, are unclear, or mostly incorrect</td>
</tr>
<tr>
<td>0</td>
<td>Causal relationships are not indicated or are all incorrect</td>
</tr>
</tbody>
</table>

Pay attention to correctness as well as numbers.

**Systems Reasoning** (adapted from Hokayem & Gotwalls, 2016, p. 10)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Contains a high degree of interconnectivity including many causal loops in multiple directions with a clear flow. Individual elements have multiple connects with clear cause and</td>
</tr>
</tbody>
</table>
effect relationships. Interconnectivity is present among most elements, not just the central idea.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Contains some interconnectivity beyond just the central idea, but the flow is less clear and more random. Some causal loops, but primarily single relationships.</td>
</tr>
<tr>
<td>1</td>
<td>Little interconnectivity and primarily only the central idea is connected to multiple elements. Primarily linear relationships.</td>
</tr>
<tr>
<td>0</td>
<td>All linear relationships with no causal loops. Very few relationships among elements leading to a sparse appearance to the map.</td>
</tr>
</tbody>
</table>

Be careful with the loops and ensure the directions are correct before you assume it’s a loop.

**Explanation of Map (Question 1)**

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>The written and drawn portion are clearly connected and the written portion helps to enhance the drawn portion.</td>
</tr>
<tr>
<td>2</td>
<td>The written and drawn portion are mostly connected but have some elements appearing in one but not the other</td>
</tr>
<tr>
<td>1</td>
<td>The written and drawn portion have few connections and few elements occur in both portions</td>
</tr>
<tr>
<td>0</td>
<td>The written and drawn portion are separate and one does not help explain the other</td>
</tr>
</tbody>
</table>

**Scientific Correctness of Explanation (in Question 1)**
<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Explanation includes a clear and correct mechanism with evidence, all scientific content is correct</td>
</tr>
<tr>
<td>2</td>
<td>Explanation includes mechanism with evidence, not entirely scientifically correct</td>
</tr>
<tr>
<td>1</td>
<td>Explanation includes a vague attempt at mechanism and evidence, and/or very little scientific content is correct</td>
</tr>
<tr>
<td>0</td>
<td>No mechanism or evidence, little to no scientific content included, vague statement like “this is my causal map”</td>
</tr>
</tbody>
</table>

Vagueness counts as being incorrect.

### Explanation to Non-Scientist (Question 2)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Refers to two or more examples from the map to describe why plants are important</td>
</tr>
<tr>
<td>2</td>
<td>Refers to one example from the map to describe why plants are important</td>
</tr>
<tr>
<td>1</td>
<td>Only refers to map in a vague and general sense; is not specific with factors and examples</td>
</tr>
<tr>
<td>0</td>
<td>Does not refer directly to any factors in map</td>
</tr>
</tbody>
</table>

Make sure examples are actually DESCRIBING importance of plants, rather than just having a “trigger” word.
References


Hershey, D. R. (2002). PAD:" we have met the enemy and he is us". *Plant Science Bulletin, 48*(3), 78-84.


Pany, P. (2014). Students’ interest in useful plants: A potential key to counteract


Parsley, K.M. Daigle, B.J., & Sabel, J.L. (In review). Development and Validation of the Plant Awareness Disparity Index to Assess Undergraduate Levels of Plant Awareness Disparity.


CHAPTER 4: CHARACTERIZING FUNCTIONAL BOTANICAL LITERACY: EXPLORING A CONCEPTUAL FRAMEWORK FOR ADDRESSING PLANT AWARENESS DISPARITY

Introduction

Plant awareness disparity (PAD) is defined as the tendency not to notice plants in an environment and includes four components: attention (not noticing plants), attitude (not liking plants), knowledge (not understanding the importance of plants), and relative interest (finding plants less interesting than animals) (Parsley, 2020; Wandersee & Schussler, 1999). This phenomenon often leads to the point of view that plants are unimportant to scientific research, the biosphere, and human affairs (Hershey, 1993). As such, PAD often leads to a negative impact on students’ ability to understand the relevance of plants to their everyday lives.

One example of this is in the case of socioscientific issues. Socioscientific issues (SSIs) are controversial scientific topics that are made up of both a scientific and social component which impacts society (Zeidler & Nichols, 2009). Because of PAD, students may have limited and narrow understandings of some botanical SSIs such as climate change, genetically modified organisms (GMOs), biofuels, and plant conservation. While some students may understand certain aspects of these SSIs in a specific context, students still have a difficult time connecting how important plants are to their everyday lives and educating students further about how botanical SSIs affect them may improve their understanding (Chapter 5; Parsley et al., in progress).
For example, PAD contributes to a lack of knowledge about illegal wildlife trade and its effects on plants and their conservation, which often leads to a lack of protections for plants (Margulies et al., 2019). Krishnan et al. (2019) have called for more food and agriculture related education efforts to reduce PAD due to ever-increasing urbanization. Amprazis and Papadopoulou (2018) called for better pedagogical coverage of plants in elementary school curricula to bring attention and awareness to their importance to human welfare and biodiversity. In a previous study, we also noted that students often do not explicitly connect botanical SSIs such as pollution with plants and people (Chapter 3; Parsley et al., in review).

Thus far, several interventions have been used in university and K-12 classrooms with the goal of reducing PAD (e.g., Fančovičová & Prokop, 2011; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman 2006; Ward, Clarke, & Horton, 2014). However, for the most part, these interventions have focused on increasing student knowledge of, and attention toward, plants (thereby excluding attitudes and interest components of PAD). A previous approach using herbal drugs and medicinal plants has been shown to engage students’ interest in, and improve student attitudes toward, plants (Pany, 2014; Pany et al., 2019). However, this approach does not address the lack of understanding of how botanical SSIs work.

To remedy this, we have developed a conceptual framework known as functional botanical literacy (FBL) (Chapter 3; Parsley et al., in review). FBL is defined as the ability to make sound, scientifically-informed decisions regarding botanical SSIs. Previously, we have explored parts of this framework in the context of causal maps in a
botany course and decision making in a science literacy and general biology course
(Chapter 3; Parsley et al., in review; Chapter 5; Parsley et al., in progress).

The aim of this paper is to describe and characterize FBL for future use in other
studies, and to demonstrate what FBL looks like in the context of a science literacy
course for mixed majors and in a general biology course for nonmajors. Using these two
course contexts will allow for comparisons between a very specific type of science
literacy course and a much more common general biology course, allowing us to identify
common aspects of FBL even in very different courses. With this information, future
studies can then explore exactly how FBL impacts PAD and whether the incorporation of
botanical SSIs improves student PAD levels. Instructors will also be able to better
understand how FBL can be observed in the classroom and what markers to use to look
for FBL in their students. To that end, we developed the following research questions:

1. To what extent do students in a science literacy course for mixed majors
demonstrate markers of functional botanical literacy?

2. To what extent do students in a general biology course for nonmajors demonstrate
markers of functional botanical literacy?

3. What comparisons can be made between FBL levels in a science literacy course
for mixed majors and FBL levels in a general biology course for nonmajors?
Conceptual Framework

Figure 1. Functional botanical literacy diagram. Functional botanical literacy (FBL) is comprised of two main components: functional scientific literacy and botanical literacy. These two components merge together to become FBL in the diagram. FSL is comprised of a combination of decision-making skills and socioscientific issues (SSIs). Within FBL, botanical literacy is combined with botanical SSIs which is reflected by the plus sign between the two components. The use of botanical literacy in combination with botanical SSIs is what sets FBL apart from FSL.

Functional Scientific Literacy

Functional scientific literacy (FSL) is a competent form of scientific literacy, meaning that it is an intermediate level of literacy between mastery and non-mastery
An intermediate form of mastery like functional scientific literacy is appropriate for undergraduate students, as they are not yet expected to be masters in scientific literacy, but they are expected to be above the beginner level and continuing to develop this literacy. Intermediate forms of science literacy typically require students to perform a specific function to demonstrate their literacy (Laugksch, 2000; Zeidler et al., 2005). In the case of FSL, the functional goal is to make sound, scientifically-informed decisions about socioscientific issues (SSIs). SSIs are a fundamental dimension of scientific literacy, and decision-making about an SSI is a common functional goal across many forms of science literacy (e.g. Alred & Dauer, 2020; Dauer et al., 2017; Roberts & Bybee, 2014; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019).

**Botanical Literacy**

Botanical literacy is defined as what students should know about plants, and is a subset of biological literacy (and, by extension, a subset of scientific literacy) (Uno, 2009). Previous research states that botanical illiteracy exists mainly due to a lack of student interest in plants, low exposure to plants throughout school years, and because students lack intellectual curiosity and rigor despite being technologically advanced (Uno, 2009). This characterization of botanical literacy is currently the only known definition of the term, making further investigation and description critical. Uno (2009) suggests that simply teaching botanical content is not the most effective way to combat botanical illiteracy. Instead, educators should prioritize using plants to teach major biological concepts, using engaging teaching methods, and utilizing plants to develop critical thinking skills. Unfortunately, students are not inherently interested in botanical
content, and PAD has a powerful negative effect on the way students think and learn about plants (Parsley, 2020; Wandersee & Schussler, 1999; Uno, 2009).

Uno (1994) noted that teachers lack the flexibility they need to move beyond strict educational guidelines in K-12 environments, and this can contribute to botanical illiteracy as well. This is especially true if botanical examples are not used for overarching biological concepts. Unfortunately, plants tend to be taught separately and in a way that does not engage student interest (Uno, 1994). The disconnect between the nature of botanical literacy and the teaching of botanical content itself is only contributing to the disparity among students who are and are not interested in plants, thereby contributing to PAD (Uno, 2009). Students who are naturally interested in plants will continue to seek them out, while those who are not will continue to avoid them at all costs (Uno, 2009). In order to mitigate this problem, educators need to find ways to engage all students’ interest in plants and use their interest as a segue into teaching botanical content that is useful and relevant to students’ lives (Uno, 2009).

**Functional Botanical Literacy**

Functional botanical literacy (FBL) is defined as the ability to make sound, scientifically-informed decisions about botanical socioscientific issues (SSIs). It is comprised of two main concepts: functional scientific literacy (FSL) and botanical literacy. FSL is defined as the ability to make sound, scientifically-informed decisions about SSIs (Laugksch, 2000). In the case of functional botanical literacy (FBL), the function that students will perform is making a decision about a botanical socioscientific issue (SSI). This specific decision-making exercise in a socioscientific context such as
biofuels is also important because the botanical SSI students will make a decision about is designed to increase their interest in, and improve their attitudes toward, plants (Chapter 3; Parsley et al., In review).

Overall, functional scientific literacy is incredibly important to FBL because it forms the theoretical and functional basis for the skills students need to be considered functionally botanically literate. Because it is concerned with decision-making in the context of SSIs, FSL is comprised of both SSIs and decision-making skills. The other main component of FBL, botanical literacy, is simply defined as what students should know about plants (Uno, 2009). In this framework, we have combined botanical SSIs and botanical literacy because the combination of botanical SSIs and botanical literacy is what sets FBL apart from FSL.

Given that FSL shares many similarities with FBL, it is important to delineate between these two concepts. FBL differs from FSL in that 1) it specifically utilizes botanical SSIs only, and 2) it incorporates botanical literacy, and thus, is only appropriate to be used in situations where efforts are being made to improve botanical education in some way. While it may also be of use in other botanical education and literacy contexts, we designed FBL primarily to address plant awareness disparity (PAD).

The development of FBL to address PAD stems from a hypothesis that the botanical SSIs in FBL could appeal to student interest in and attitudes toward plants, potentially laying the groundwork for addressing PAD from a different starting point. PAD is made up of four components: attention, attitude, knowledge, and relative interest (Parsley, 2020; Wandersee & Schussler, 1999). Attention is the idea that students do not
notice plants in their environment, and this component forms the basis for the original
definition of PAD. **Attitude** refers to the phenomenon wherein students do not like plants,
and do not enjoy learning about them. **Knowledge** is made up of students’ understanding
(or lack thereof) about plants, particularly knowledge of the importance of plants.
**Relative interest** refers to the fact that students tend to demonstrate more interest in
animals than they do in plants. Previous interventions for PAD tend to target or measure
the attention and knowledge components over the attitude and relative interest
components (e.g., Fancovicova & Prokop, 2011; Strgar, 2007; Wandersee, 1986;
Wandersee, Clary, & Guzman 2006; Ward, Clarke, & Horton, 2014). However, FBL is
unique in that it instead targets student interest and attitudes through the use of botanical
SSIs.

However, it is important to note that FBL could be used in other botanical
education contexts beyond PAD. While this is certainly a possibility for future studies,
the use of FBL in other contexts is beyond the scope of this work, as we are currently
primarily concerned with the development and characterization of FBL. It is also
important to note that while FBL was designed to address PAD, this work is prioritizing
the development and characterization of FBL rather than exploring potential relationships
between FBL and PAD. The reasoning for this is that, while we know what PAD is and
how it is characterized, we do not have this information for FBL. Therefore, it is
important to lay the theoretical groundwork for FBL before exploring how FBL may
affect PAD (and vice versa).

Despite the research conducted and the development of engaging ideas about how
to improve botany education, researchers and educators still need a way to help students
understand plants’ relevance to everyday life and their importance to humans. Our research contributes a potential solution to this problem with the development and characterization of FBL. In this paper, we will further describe what FBL looks like in the context of a science literacy course for mixed majors and a general biology course for nonmajors. As both of these courses included botanical education (both included units relating to plants), and both of them utilize a botanical SSI, both are relevant to the description and definition of FBL given above.

**Methods**

**Course Context**

The science literacy course at the University of Nebraska-Lincoln (UNL; N = 113) included both STEM and non-STEM majors. It was a required course for primarily first-year undergraduate students within the College of Agricultural Sciences and Natural Resources and focused on contemporary food, energy, and water issues. The entire course was structured to support students to gain scientific literacy and experience in evaluating issues and making decisions regarding SSIs. The course was split into four units which were each approximately four weeks long. The unit of focus for this study was about biofuels. In the UNL course, students participated in active-learning lecture, small-group discussions, and assignments to evaluate criteria related to biofuels and to structure their final decision.

The general biology course at the University of Memphis (UofM) (N= 119 students) included primarily non-STEM majors and was one option for the general education requirement of all students at the university. The course was a more traditional
non-majors biology course that covered cell structure and function, genetics, and evolution topics. Each unit also included a Real World Scenario in which students were required to consider how the science content fits into situations they may encounter outside of the classroom (Sabel & Sorin, in review). In particular, as an addition to the photosynthesis content, it included a biofuels section modeled after the unit developed at UNL. At UofM, students spent only three days on the biofuels content and decision-making.

The UNL course utilized a highly scaffolded approach so that background information was presented along with the decision-making framework. Students were given the criteria and options (see below) in each decision and asked to weigh those criteria based on their level of importance to each student (See Appendix A). Then options for a solution to the SSI problem were weighted based on how well they addressed each criterion. In the biofuels unit, students were presented with four options and four criteria but asked to weigh only two of these options and criteria. As the course progressed, they learned how to weigh all four options against all four criteria in the unit at the end of the course. Additionally, the beginning of the course covered fast and slow thinking, the decision-making framework that students used all semester, what criteria are and how to weigh them, as well as what options are and how to evaluate them (Kahneman, 2011). There was also a great deal of instruction focused on how to find and evaluate different types of scientific literature and information as part of the research process associated with finding options for solutions.

None of this scaffolding existed in the UofM course, as it was a content-based course rather than a decision-making course. Students completed only one decision-
making activity and it was during the biofuels unit that was associated with photosynthesis class content. Fast and slow thinking was covered in the course, along with information about criteria, options, and the decision-making framework that was also present at UNL (Kahneman, 2011). Students were asked to come up with their own options and criteria and weigh them.

**Data Collection**

To carry out this research, we collected the biofuels module assessment from UNL which provides students with four options for how to solve the problem of which biofuels work best to replace fossil fuels: status quo: gasoline and diesel are dominant, support second generation biofuels (corn stover, sorghum, switchgrass, etc.), promote and subsidize electric cars and renewable electricity, and educate and motivate to drive less and fly less (Alred & Dauer, 2020; Alred & Dauer, in press; See Appendix A). The criteria the students used to evaluate these options were: fewest greenhouse gas (CO₂, e.g.) emissions, economic benefit to farmers & rural communities, preserve the health of natural resources (land, water, soil, biodiversity, air quality), and cheapest for people at the gas pump and for vehicle purchases.

The assignment required students to research all of the assigned options for how well they meet the assigned criteria. Throughout the course, students were given several opportunities to do this kind of research with instructor feedback. The assignment then required students to rank each option based on how well it satisfied each criterion, and then weigh each criterion based on how important it was to the student. Based on this process of ranking and weighing options and criteria, students were then asked to make a
decision among the four options based on how well it addressed each criterion and how important those criteria were to the student. Finally, students were asked to elaborate on the rationale behind why they chose that specific option as a solution.

At the UofM, we collected the student essays which are an extended version of a group decision activity modeled after the UNL module assessments (Chapter 5; Parsley et al., in progress; See Appendix B). The group decision activities posed the same problem, but asked students to come up with their own options and criteria rather than assigning options and criteria for the students to use. Students used the same process to score and weigh each option and criterion as the assignment at UNL. The essays extended this task and asked whether or not the student agreed or disagreed with their group during the decision-making process and what their opinions were if the student disagreed with their group. Essays were assigned at the end of the photosynthesis portion of the course.

Finally, we conducted interviews both at the UNL and UofM. There were nine participants at UNL and ten at UofM. Participants were selected based on a range of PAD levels using the Plant Awareness Disparity Index (PAD-I; Chapter 2, Parsley et al., in review). The survey was 25 items long and has been shown to be reliable and valid with a six factor structure (Chapter 2; Parsley et al., in review). The interviews were conducted by the first author in person and lasted approximately one hour. The interview questions were primarily about students’ ideas regarding plants and biofuels and asked questions such as, “What are biofuels?” “Do you think biofuels are an important topic to learn about?” “Do you think we should switch to using more biofuels instead of fossil fuels?” and, “What internal and external factors affect the way you think about biofuels?” (See
Appendix C). All interviews were transcribed and then analyzed using Atlas.Ti Qualitative Coding Software.

**Data Analysis**

To address the first research question, we analyzed the UNL module assessments and interview transcripts to look for all decisions regarding biofuels, the rationales behind these decisions, and any scientific information used in these rationales. Because the goal of FBL is for students to make sound, scientifically-informed decisions, we chose to break these decisions down into three components that could be analyzed for scientific validity and information: the decisions themselves, rationales behind the decisions, and scientific information used in the rationales. Once we isolated these components, we deductively coded the decisions and whether or not they were scientifically informed (Table 1). We inductively coded rationales based on whether they were based upon science, the students’ values, convenience of the decided-upon solution, cost, or other factors (Saldana, 2015; Table 1). Finally, we deductively coded any scientific information used in the rationales for whether or not it was a misconception or a misunderstanding of a concept (Table 1) (Saldana, 2015). We repeated this process for the UNL module assessments, the UofM essay assignments, and the interviews conducted at both universities.

**Utilizing Decision Components as Markers of FBL**

Each component we analyzed in this study originated from our definition of FBL: the ability to make sound scientifically-informed decisions regarding botanical SSIs. We decided to break this definition down into three components: decisions, rationales, and
scientific information. The first part of FBL is the scientifically-informed decision. Any decision that did not prioritize using fossil fuels was considered scientifically-informed. Decisions that were considered not scientifically-informed were those that chose to keep things the way they are (the status quo option of the assignment) as current scientific knowledge indicates that climate change is worsening and biofuels should be pursued to help mitigate this issue. This concept is also taught in the course itself. If students chose to keep things as they are and continue using fossil fuels, this would be an indication that students are lacking in FBL as they have opted for a decision that is not scientifically-informed.

In order to better determine if the decisions were scientifically-informed, we chose not to just evaluate the decisions themselves, but to also include the rationales behind these decisions. If students cite science in their rationales, this is a potential indicator that they are developing FBL. If students made what appears to be a scientifically-informed decision on the surface, but cited reasons other than scientific information, they are not demonstrating the full definition of FBL.

Finally, though misconceptions are not mentioned in our conceptual framework, we determined that it was important to evaluate students’ choices of scientific information that supported their decisions to see if they contained any misinformation. If students based a decision upon misconceptions, it would negatively impact the validity of the scientific information used in the decision, and by extension, the scientific validity of the decision itself. This would also disqualify the students’ decision as being considered aligned with FBL.
Table 1.

*Coding and Evaluation Approach to Determine if Students Demonstrate FBL*

<table>
<thead>
<tr>
<th>Component of Intervention</th>
<th>How to Evaluate Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision itself</td>
<td><em>Is their decision scientifically valid?</em> A decision that does not utilize fossil fuels is considered scientifically valid, due to the damage fossil fuels do to the environment and students’ knowledge of this fact.</td>
</tr>
<tr>
<td>Rationale for decision</td>
<td><em>Is there scientific information present in the rationale for their decision?</em> This indicates whether the decision was scientifically-informed.</td>
</tr>
<tr>
<td>Scientific information</td>
<td><em>Is the scientific information used in the rationale correct?</em></td>
</tr>
<tr>
<td>within rationale (if present)</td>
<td>Misconceptions indicate that the student was using incorrect information to make their decision, negatively impacting the validity of the information and the student’s decision in the process.</td>
</tr>
</tbody>
</table>

**Results**

**Evaluating the Decisions in UNL Module Assessments**

In the first research question, we asked, “To what extent do students in a science literacy course for mixed majors demonstrate hallmarks of functional botanical literacy?” To answer this, we evaluated the decisions made as part of the module assessments at UNL to determine how many students chose a scientifically-informed option as their final
decision. Examples of scientifically-informed decisions included, “support second generation biofuels (corn stover, sorghum, switchgrass, etc.),” “promote and subsidize electric cars and renewable electricity,” and, “educate and motivate to drive less and fly less.” Our reasoning for considering these answers to be scientifically-informed is that they do not include fossil fuels, which would indicate that students were not using scientific information in their decision, as the science and course content states that fossil fuels are damaging to the environment. As the point of FBL is for students to make sound, scientifically-informed decisions about botanical SSIs, we decided this would be the most optimal way to determine if the decisions themselves reflected this goal.

We found that 68 out of 74 total participants chose an option that was scientifically informed, while six participants chose an option that was not scientifically informed (Table 2). The option that was considered as not scientifically informed was status quo: gasoline and diesel are dominant. Five students made a decision but indicated that they were not entirely satisfied with the options presented and struggled to make a choice (Table 2).
Table 2.

*Codes and frequencies for UNL module assessment decisions with examples.*

<table>
<thead>
<tr>
<th>Decision Category</th>
<th>Frequency (out of 74 decisions)</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientifically valid</td>
<td>68</td>
<td>“Support second generation biofuels (corn stover, sorghum, switchgrass, etc.),”</td>
</tr>
<tr>
<td>Not supported by science</td>
<td>6</td>
<td>“Status quo: gasoline and diesel are dominant,”</td>
</tr>
<tr>
<td>Chose an option but hesitated/was indecisive</td>
<td>5</td>
<td>“I cannot choose a best option, not a one solved the problems presented. The least invasive idea is option 4 [educate and motivate to drive and fly less].”</td>
</tr>
</tbody>
</table>

**Evaluating the Rationales in UNL Module Assessments**

To further understand why students made these decisions and how scientific information played a role in them, we also evaluated the rationales included in the assignments to determine what reasons were present. We found that the most common rationales were science-related, and often cited reasons such as climate change, greenhouse gas emissions, environmental concerns, and renewability/sustainability of the fuel source (See Appendix D). This is likely because of the research students were required to do to evaluate how each option satisfied each criterion. The status quo option
does not do a good job of satisfying the reduction of greenhouse gas emissions criterion as keeping the status quo will only increase greenhouse gas emissions. The inclusion of scientific information as rationales behind their decisions is an indicator that students could be developing FBL, as scientifically-informed decisions regarding botanical SSIs is the ultimate goal of FBL.

Following this, the most common rationale response was directly referencing the structure of the module assessments themselves (See Appendix D). Students often referred back to the criteria and performance scores to justify why they chose a particular option. Given the structure inherent in the module assessments, these performance scores often demonstrated the students’ priorities in evaluating how well each option fit the criteria. Therefore, it is unsurprising that students relied so heavily upon them to justify their decisions. This could be evidence that the structure of the assignment itself also has an impact on student decision-making.

Closely following the criteria and performance scores, the impact upon farmers was a highly cited reason for the way students made their decisions (See Appendix D). Given that UNL is a land grant institution that is also located in the Midwest, this may be because many students know, are related to, or have worked as farmers at some point in their lives. Farmers are important stakeholders when it comes to biofuels as in many cases, they would be responsible for growing the crops used for biofuel. It is possible that the personal experiences of students at UNL may have played a role in their decision-making. However, without more data, it is difficult to tell if this is actually true. This particular result may point to a need for more information on how personal experiences and backgrounds influence student decision-making.
Evaluating Scientific Information used by Students in UNL Module Assessments

Finally, we evaluated the scientific information used in the rationales to determine whether or not they were misconceptions. By and large, the scientific information that students used was reliable and not a misconception. This is likely because students at UNL had multiple opportunities to research the criteria and get instructor feedback on how well they were applying that information. There were no outright misconceptions present in the module assessments, but there were mixed answers that included some correct information mixed in with some misinformation. This misinformation was often regarding how biofuels work or what parts of crops are used for biofuels, as was the case when one student said, “Farmers and rural communities will benefit by getting dual profits off of the crop and the crop’s waste because second generation biofuels only use waste of crops.” (Table 3). This statement is not entirely accurate as second-generation biofuels often use entire crops such as switchgrass and are not limited solely to using the waste of food crops. While it is encouraging that no answers were entirely comprised of misconceptions, it is worth noting that the misunderstanding of how certain biofuels are produced could lead to scientifically-inaccurate answers (answers not backed by correct scientific information) and therefore negatively impact FBL. However, given that very few answers included these misconceptions, we maintain that the class at UNL demonstrates a high frequency of FBL markers.
Table 3.

*Codes and frequencies for UNL module assessment scientific information with examples.*

<table>
<thead>
<tr>
<th>Category of Scientific Information</th>
<th>Frequency</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct information</td>
<td>53</td>
<td>“Government support for second-generation biofuels is best done by investing in research and development or by subsidizing them. This action could inspire people to better develop and perfect biofuels as an alternative to fossil fuels to reduce greenhouse gas emissions.”</td>
</tr>
<tr>
<td>Both correct and incorrect information present</td>
<td>1</td>
<td>“Second generation biofuels can help rural economy and farmers when the funding for research is increased. It would not do best in promoting electric vehicles or motivating the public to drive and fly less. Farmers and rural communities will benefit by getting dual profits off of the crop and the crop’s waste because second generation biofuels only use waste of crops.”</td>
</tr>
</tbody>
</table>
FBL Present in UNL Module Assessments

Overall, it appears that the students in the course at UNL demonstrated several hallmarks of FBL, as they demonstrated a high frequency of scientifically-informed decisions, scientific information present in rationales, and a low frequency of misconceptions within those rationales. All of these are indicative of FBL as the ultimate goal of FBL is a scientifically-informed decision regarding a botanical SSI in the context of botany education (the course at UNL satisfies the latter requirements with the biofuels unit). The majority of their decisions were scientifically informed, and none of the scientific information that informed those decisions was comprised entirely of misconceptions or misinformation. One answer contained a detail that was incorrect within some of the scientific information but did not contain major misconceptions. The rationales were largely informed by science, but other reasons were present as well. This indicates that while the students did demonstrate markers of FBL, their personal values and experiences also played a major role. It appears that having a highly-structured assignment and course with built-in rigorous scientific research has a very effective impact on the skills needed to develop FBL.

Evaluating the Decisions in the UofM Essay Assignments

In the second research question, we asked, “To what extent do students in a general biology course for nonmajors demonstrate hallmarks of functional botanical literacy?” To answer this, we followed the same steps as outlined above with the UNL course. We found that the UofM course also demonstrated high levels of scientifically-informed decisions, with 76 out of 95 decisions using science. Many of these cited using
corn ethanol or algae as biofuels, as these two were presented as options during the biofuels unit. For example, one student noted, “Corn ethanol became our best solution because it is less damaging than fossil fuels and is also cheaper.” These are still considered to be scientifically-informed, as they do not involve using fossil fuels which students learned are damaging to the environment. It is noteworthy that both algae and corn ethanol were discussed at length during the biofuels unit and algae as a biofuel was a focus of the textbook chapter (Shuster et al., 2017). So while these decisions are considered scientifically-informed, it may be that students chose them out of familiarity.

However, 19 out of 95 students did not make a scientifically-informed decision. For example, one student responded, “My decision was to use less corn ethanol because it decreases the food source of corn and it would be better for the land. My decision wasn’t different from the group’s decision because most of us agreed and we read the articles and helped with the decision.” While this idea may reduce the problems inherent in the food versus fuel debate, it does not actually solve the problem at hand: that of finding an appropriate replacement for fossil fuels. The food versus fuel debate is the idea that the more crops we grow for fuel, the less we may have for food. As such, more of an emphasis on the research surrounding how fossil fuels affect climate change may be necessary. Students may require further clarification that the goal is to find a solution for greenhouse gas emissions caused by fossil fuels, rather than focusing all their efforts on the food versus fuel problem.

Fourteen essay answers were hesitant or indecisive, as evidenced when one student said, “My decision varied with the rest of the group. I believe that we need to find a happy medium between pushing biofuels or corn ethanol and regular gas,” (Table 4).
(Note that these counts are actual decisions, not students, as each essay includes multiple decisions by the student who wrote it.) These students were not as motivated by the science surrounding how fossil fuels impact the environment, and instead wavered between priorities such as environmental concern and cost for consumers. While there were larger numbers of indecisive and non-scientifically-informed decisions at UofM as compared to UNL, the majority of the decisions made during this assignment at UofM were still scientifically-informed in some way. This is noteworthy in that it demonstrates potential for even short-term interventions having an effect on student FBL.
Table 4.

*Codes and frequencies for UofM essay decisions with examples.*

<table>
<thead>
<tr>
<th>Decision Category</th>
<th>Frequency</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientifically informed</td>
<td>76</td>
<td>“The options we came up with for how to produce biofuel consisted of using algae, developing alternative methods in biofuel production, keeping the means of production the same cutting down on the use of corn in biofuel production, and making the switch to electric cars. After much deliberation and filling out the table, we arrived at the conclusion that algae would be the best option based on our criteria.”</td>
</tr>
<tr>
<td>Not scientifically informed</td>
<td>19</td>
<td>“It is for these reasons I believe we should keep using gasoline, as well as make natural gas more of a common fuel.”</td>
</tr>
<tr>
<td>Indecisive/hesitation</td>
<td>14</td>
<td>“The only decision that I made was that we needed to see it from all aspects.”</td>
</tr>
</tbody>
</table>
Evaluating the Rationales in UofM Essay Assignments

To determine students’ reasoning behind their decisions, we evaluated the rationales behind each decision. This allowed us to determine how many of the rationales were scientifically-driven versus driven by other motivations. Scientifically-driven rationales can also be considered markers of FBL as they reflect the ultimate goal of FBL: a scientifically-informed decision about a botanical SSI. Citing science in students’ rationales behind their decisions potentially points to students gaining FBL. We found that scientific rationales were the most common by far, often citing reasons such as climate change, greenhouse gas emissions, pollution, renewability and sustainability, etc. This again points to students using the scientific information presented to them in class. At the UofM, students were not only asked to read their textbook which contained a story about algae as biofuel, they were also provided with articles about corn ethanol and its benefits and drawbacks. The instruction surrounding how each biofuel influences greenhouse gas emissions and environmental concerns may have played a role in these rationales.

Following this, students often cited cost as a common reason for their decision (See Appendix E). This usually referred to the cost to the consumer, especially regarding fuel prices. For example, one student noted, “My decision was to continue using corn ethanol and to encourage the government to increase the amount of it required to be mixed with natural gas. We came to this decision because despite disadvantages of corn compared to other cleaner biofuels, the infrastructure for creating corn ethanol has already been paid for and built.” Cost was so important that, in this situation, the student opted for a less-than-optimal option simply because it would cost less to the consumers.
This consideration of cost differs from the UNL course (which cited the weighted performance scores of the criteria second most often).

Following cost, the most popular rationale was the people (or stakeholders) that would be affected by the decision. This often included consumers, farmers, and sometimes those who work in the oil industry (as switching to biofuels may cause a reduction in jobs in fossil fuels industries). This is similar to the third-most-common response at UNL, as students there often made the point that farmers are likely to be affected by their decisions. Students at UofM had the same concern regarding stakeholders but expanded it beyond just agricultural impacts to include others who had a vested interest in the oil industry.

**Evaluating the Scientific Information used in UofM Essay Assignments**

Lastly, we examined the quality of the scientific information being used in the student decisions at UofM and found some discrepancies between UofM and UNL. At UNL, the vast majority of the scientific information was entirely correct, and only one response included a minor misconception about where biofuels come from. At UofM, however, there were a few responses based on misconceptions alone, and a higher proportion of responses with both correct and incorrect information present (Table 5). For example, one student argued for natural gas as a viable option, “Natural gas is cheaper than gasoline and achieves slightly less efficiency than gasoline while not impacting the environment nearly as much, it’s a much cleaner burn.” However, natural gas also gives off greenhouse gas emissions and is therefore not a great alternative to fossil fuels (especially given that it is a fossil fuel, too). It would appear this person is
confused about what qualifies as a fossil fuel, and the misconception that natural gas is somehow cleaner may be related to the fact that we refer to it as natural. This could be confusing the student into thinking natural gas is somehow a biofuel. The presence of this misconception also has an impact on the scientific validity of their decision to choose natural gas. Perhaps if they understood that natural gas is a fossil fuel, they may have chosen a different, more scientifically-informed decision. In this particular instance, the student is demonstrating a lack of FBL and it could be entirely because of a misconception, which is precisely why looking at the scientific information used in the decision is so important.

Additionally, there was an occasional response that cherry-picked scientific information. In this case, one student (in two decisions) chose only to look at data regarding how efficient fossil fuels are, rather than also taking into account environmental concerns the way the rest of the biofuels intervention did. This particular student focused on his own experiences as a relative of two engineers and used data to back up his opinions (Table 6). While this does indicate a certain level of skill in finding scientific research, it is important to note that FBL skills used in this way often lead to more misconceptions and misunderstandings when all scientific data and concerns are not addressed. While the student (in the strictest sense) is making a scientifically-informed decision, it may not be a sound decision as it relies on different scientific information than what was intended. Therefore, it may be necessary for instructors to be careful in how they present scientific information and explain what types of information are relevant to each decision. In this case, the student only identifies efficiency of fuel as being relevant and neglects environmental data.
Table 5.

*Codes and frequencies for UofM essay scientific information with examples.*

<table>
<thead>
<tr>
<th>Scientific Information Code</th>
<th>Frequency</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct information</td>
<td>48</td>
<td>“Everyone in the group agreed that using algae as an energy source would be incredibly convenient and ecofriendly, so we all decided to make research and implementation of algae energy a high priority in our analysis. The papers drastically changed our opinion on biofuel, as we were previously in support of corn-based biofuel before we were aware of the corn shortage and also the possible environmental detriments.”</td>
</tr>
<tr>
<td>Misconception</td>
<td>3</td>
<td>“My group came to the conclusion that we should try to use higher percentage ethanol fuel as electric and other alternatives are simply not possible at the moment, however my opinion is different.”</td>
</tr>
</tbody>
</table>
Uses science but ignores certain types of research

“Growing up the son and grandson of two Georgia Tech engineers, I have had many conversations about fuel types over the course of my life. Ethanol is a very inefficient source of energy and actually requires more energy to produce than it can produce itself, not including the additional energy to produce the crops. According to Cornell agricultural professor David Pimentel, “producing ethanol actually creates a net energy loss. His research shows that a gallon of ethanol contains 77,000 BTUs of energy for engines to burn but requires 131,000 BTUs to process into usable fuel, not including additional BTUs burned from fossil fuel sources to power the farm equipment to grow the corn, and the barges, trains and trucks used to transport it to refineries and ultimately fueling stations.” Travelling to Georgia for a funeral I was able to purchase ethanol-free gasoline in Mississippi and was able to achieve 37mpg on my vehicle as opposed to my usual 31 for purely interstate travel.”

Both correct and incorrect conceptions present

“My group felt algae was a smart option for increasing biofuel diversity because it takes less energy to turn it into ethanol than it takes for corn. In the articles my group also learned that corn is very demanding of soil.”
FBL Present in UofM Essay Assignments

Overall, it would appear that although the students at UofM do demonstrate markers of FBL, they do not do so to the same extent as do the students at UNL. This is demonstrated by a lower frequency of scientifically-informed decisions, some decisions being entirely informed by misconceptions, and a higher frequency of decision rationales including both correct and incorrect information. Considering the differing goals of each course, as well as the structure of the courses and their assignments, this is not altogether unexpected. However, it does shed light on the fact that instructors can improve FBL skills in students without having to completely change the format and structure of their course. Even one intervention in a traditional biology course can improve the skills necessary for students to gain FBL. However, students at the UNL course demonstrated higher frequencies of FBL markers, indicating that longer interventions are more likely to be successful to a higher degree.

Evaluating the Decisions in Interviews across Both Courses

In the third research question we asked, “What comparisons can be made between FBL levels in a science literacy course for mixed majors and FBL levels in a general biology course for nonmajors?” At both UNL and UofM, the decisions students were asked to make during interviews were largely scientifically informed. Almost all of these decisions involved using biofuels in some way and either transitioning away from fossil fuels gradually or immediately changing to some sort of biofuel. Many students chose to make a slow transition but understood that a transition was necessary because of environmental and renewability concerns (Table 6). There were only a few responses in
either course that were not scientifically informed. This indicates that in both courses, during the interviews, students were demonstrating markers of FBL as well despite these interviews being outside the context of an assignment.

However, there was a higher proportion of indecisive responses from students in both courses. This may be due to the fact that interviews were less structured and did not have an impact on student grades (as the assignments did), so students were less motivated to commit to a decision. UofM had a higher frequency and proportion of all three categories of decisions, indicating that participant number was not the only factor when considering differences in interview decisions between each course. One reason may be that students at UofM were more open and talkative during interviews, or that they changed their minds more often (resulting in more decisions). However, without more information, it is unclear what variables affected this result.
Table 6.

*Codes and frequencies for UNL and UofM interview decisions with examples.*

<table>
<thead>
<tr>
<th>Decision Code</th>
<th>UNL frequency</th>
<th>UofM Frequency</th>
<th>Total Frequency</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientifically informed</td>
<td>15</td>
<td>19</td>
<td>34</td>
<td>“I do [think we should use biofuels] because I personally think we should start to move away from fossil fuels, especially since they’re a non-renewable source and biofuels seem to be more renewable.”</td>
</tr>
<tr>
<td>Not scientifically informed</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>“Well, that’s what I was going to say. I have no idea what an alternative would be. We used to use steam engines. But obviously, we went away from that because it honestly, I don’t know why we went away from it. Okay. Seems like a brilliant idea to me to use water instead of gas.”</td>
</tr>
</tbody>
</table>
“I do because I personally think we should start to move away from fossil fuels, especially since they’re a non-renewable source and biofuels seem to be more renewable. But I also think it’s definitely important to do more research on them and see what effect they have. Because we might think they’re better just because of this initial stuff, but... And I think this has happened, not a lot, but where people think it’s a better option. But it turns out a few years down the road that they could have very damaging effects.”
Evaluating the Rationales in Interviews across Both Courses

Across both sets of interviews, scientific information was once again the most popular rationale behind students’ decisions (See Appendix F). It is noteworthy that UNL students tended to use this rationale more often than UofM students did, as this could indicate the increased effect of a longer decision-making intervention upon FBL markers. Regardless, UofM still used science as the most common reason behind their choices as UNL did. The second most common reason was class information. This could arguably be included in scientific information, but we chose to differentiate between the two in order to better delineate what was due to the assignment itself versus what was due to students’ research. Scientific information in general was the most common, but scientific information specific to class was the second most common. This is interesting because it suggests that all scientific information — both in class and out of class — makes a difference in some way. However, the scientific information presented in class was important enough to mention specifically. This indicates that class experience potentially plays a role in the development of markers of FBL, regardless of whether the class is geared toward science literacy or not. This is another important indication that students can improve their FBL skills in any class, given the right tools to do so (and given that the class includes botany education and a botanical SSI of some sort, as these requirements are central to FBL).

Following these two rationales, there were no more explanations that are equally popular across UNL and UofM. The next most common rationale at UofM was social media, indicating that students’ decisions are impacted by what they read and see on websites outside of class such as Twitter, Facebook, Instagram, and even Snapchat. The
next most common rationale at UNL was personal motivations (or how biofuels affect the student personally). Both of these rationales are important to discuss, as personal motivations and social media can lead to students prioritizing other ideas over scientific information in their decisions based on our data.

**Evaluating the Scientific Information in Interviews across Both Courses**

The scientific information present in interviews was largely correct, which may be due to the fact that students were given the chance to explain and clarify their answers in a way that may not have been possible during the assignments (Table 7). There was one response at UNL that contained both correct and incorrect information. However, the same pattern holds true from the assignment data, as the incorrect information was a relatively minor mistake. The student misunderstood that not all second-generation biofuels are made from waste of agricultural crops.
Table 7.

*Codes and frequencies for UNL and UofM interview scientific information with examples.*

<table>
<thead>
<tr>
<th>Scientific Info</th>
<th>Code</th>
<th>UNL</th>
<th>UofM</th>
<th>Total</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct information</td>
<td>Correct</td>
<td>16</td>
<td>16</td>
<td>32</td>
<td>“Just because it is a renewable resource, so it never runs out and it comes from the environment so it’s less hurting it.”</td>
</tr>
<tr>
<td>Both correct information and misconceptions are present</td>
<td>Both correct</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>“Well, I’ve had a couple of different classes where we talked about biofuels. So when I originally went in I didn’t really know a whole lot. I think researching them. An external thing would be reading about them. That definitely helps me for sure know about it and then form an opinion on them. And I guess there’s definitely pros and cons of biofuels. I think taking all those into consideration really helps form a more educated opinion a little bit. One of the cons I think I saw one time was studies tried to say, “Oh, they actually...”</td>
</tr>
</tbody>
</table>
don’t help with greenhouse gases,” or something like that. I don’t really remember. Then I take in my personal views about how I view the environment and how I value it. We really take both of those things into consideration. I think just getting more information really helps us solidify an opinion on those things. I guess it can be a mix of both. What I see and then how I interpret it personally.”
FBL Present in Interviews across Both Courses

Across both universities and all three data sources, students demonstrated valuable skills and hallmarks of FBL. The assignment data indicate that UNL students demonstrated FBL to a larger extent than that of UofM students, due to an increased number of scientifically-informed decisions, rationales, and correct conceptions within the scientific information used in decisions. When considering numbers only in the interview data, UofM had a higher occurrence of scientifically-valid decisions (19 at UofM versus 15 at UNL) and a higher proportional rate of scientifically-valid decisions (1.9 versus 1.7 at UNL). Both courses were equal in the number of correct information used in their decision (16 in both cases), but proportionally, UNL did better (1.7 versus 1.6 at UofM).

Additionally, when considering the content of the rationales, UNL had more data indicating students there used scientific information in their decisions more often than UofM students did. The finding regarding scientific rationales is noteworthy considering again that UofM had one more participant than UNL, and therefore UofM responses were more likely to have outnumbered those from UNL. Both the interview data indicate that the science literacy course did better regarding the use of scientific information, while the general biology course did better regarding sheer number of valid decisions.

The interview data conflicts somewhat with that of the assignment data, as some markers of FBL (scientifically-informed decisions) were higher at UofM, while other markers (rationales citing scientific information and the correctness of that scientific information) were higher at UNL. The assignment data differs from this by
demonstrating that overall, UNL had higher frequencies of all three FBL markers (scientifically-informed decisions, rationales citing scientific information, and correctness of information cited in rationales). Without further data it is difficult to tell exactly what caused these differences in results.

Discussion

In this paper, we have described and characterized FBL in the context of both a science literacy course for mixed majors and a general biology course for non-majors. This conceptual framework will help to narrow down the previously confusing definition of botanical literacy (Uno, 2009). Previous work regarding FBL has built upon established theory regarding functional scientific literacy and developed FBL as a conceptual framework (Chapter 3; Parsley et al., in review; Chapter 5; Parsley et al., in progress; Zeidler & Nichols, 2009).

Across all three data sources (UNL module assessments, UofM essays, and interviews in both courses), students in both courses demonstrated markers of FBL. A majority of students in both courses and across all data sets chose scientifically-informed decisions as their response to the problem of continuing fossil fuel usage. Students often cited scientific information—sometimes directly referencing course materials—in the rationales behind their decisions. These findings reinforce the idea that course context has an impact on student decision-making (Parsley et al., in progress). This finding is further reinforced by the fact that students in the science literacy class at UNL demonstrated higher levels of FBL than those at UofM did, indicating that the course design itself also improved students’ FBL.
The presence of rationales based entirely on scientific misinformation is relatively low across both courses, indicating that students are generally using reliable scientific information to inform their decisions. UNL only demonstrated misconceptions combined with correct scientific information, indicating that they have a relatively stable grasp of the science behind biofuels while still struggling with some minor details. Alternatively, the UofM did demonstrate some major misconceptions, albeit in a low proportion compared to their correct conceptions. The relatively low proportion of these misconceptions is still encouraging, especially given that students at UofM had three days to complete the biofuels unit, and students at UNL had four weeks. Misconceptions could be mitigated further if the biofuels unit were longer at the UofM or if students were exposed to more research regarding biofuels.

Of the two courses, students in the UNL course demonstrated more hallmarks of FBL when considering the assignment data. This is unsurprising given the goal of the course is to improve students’ science literacy and decision-making skills. However, students in the UofM course, while not as functionally botanically literate as in the UNL course, still demonstrate some of these skills. This is noteworthy as it indicates that even one intervention can have an impact on students’ levels of FBL. It is important to note that the intervention needs to be fairly targeted to ensure that students gain the skills they need to demonstrate higher levels of FBL. This paper and its findings should contribute to educators’ ability to develop such targeted interventions, as the findings we describe here will help educators understand what markers indicate developing FBL.

While the assignment-based findings were relatively straightforward, the interview data tell a slightly more complicated story. We found a higher proportion of
scientifically-informed decisions present in the UofM data than in the UNL data.

However, the assignment data regarding scientific information is echoed by the interview data, where UNL students (while scoring equally in number) did proportionally better at using correct scientific conceptions in their rationales. It would seem that while students at the UofM made proportionally more scientifically-valid decisions than those at UNL did, they simply did not use scientific information as often as UNL students did in their rationales.

The assignment data and interview data demonstrate some disparities in what they say about student FBL levels within each course. One possible explanation for these differences is that the interviews were more open-ended, and as such, gave students the ability to clarify their points and be more flexible with their ideas. Thus, a slightly more structured interview protocol may be helpful in future studies exploring this framework. It may also be the case that interviews work differently than assignments in demonstrating student skills and competencies.

Another explanation is that, because the interviews were not assignments (and therefore did not have an impact on students’ grades), students answered differently than they would if their grade depended upon a certain answer. It may be that due to interviews being more flexible, open-ended, and having no influence on student grades, the interview data we collected is of a different nature than that of assignment data. If this is true, then it would seem that using decision-making assignments may result in a different answer than what the student would choose outside of the classroom. Although the assignments in each course were not graded on a right or wrong basis, the pressure of performing these activities during a class where students are being graded may have an
effect on their answers. Despite the differences when comparing interview and assignment data within each course, it is encouraging to see that across data sources, the majority of responses demonstrated hallmarks of FBL.

Overall, the most noteworthy contribution of this work is that even one intervention (designed to target the specific skills associated with FBL) resulted in students demonstrating markers of FBL, not only in a science literacy focused course for mixed majors, but also in a general biology course for nonmajors. It is not necessary to restructure an entire course to provide students with a comprehensive decision-making and science literacy pedagogical experience, though this does provide extra benefits to students as evidenced by the overall higher levels of FBL at UNL. However, given that many biology courses are restricted by university and departmental curriculum expectations, a short intervention like the one used at UofM is more easily accessible.

Additionally, this work describes and characterizes FBL more holistically, which gives instructors and researchers a better idea of what to look for to evaluate FBL in their own students. This can empower instructors to design other targeted interventions and evaluations for FBL as well. Indeed, designing targeted assessments for FBL may be highly necessary, given that the interviews yielded slightly different findings for students’ FBL levels than the assignment data did. If the interviews allowed for students to better clarify their points and use more scientific information, perhaps a more open-ended assignment and intervention is appropriate in the future. Alternatively, perhaps a more structured interview protocol could be used to better elucidate students’ ideas surrounding FBL.
Lastly, this paper contributes an overall approach to evaluating FBL within assignments and interview data: evaluating student decisions for scientific validity, their rationales for scientific information, and their choice of scientific information for misconceptions and alternative conceptions. These markers for evaluation will provide instructors with a common starting point from which they can design their interventions and assessments related to FBL. More work is needed to have a standardized approach to evaluating FBL, but having these markers as a starting point can help equip more instructors with the ability to spread these skills to more students in any course context.

Before FBL was established, research in the field of PAD primarily focused upon developing interventions to reduce this phenomenon in students at both the K-12 and university levels (e.g., Fančovičová & Prokop, 2011; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman 2006; Ward, Clarke, & Horton, 2014). However, due to the difficulties associated with targeting the knowledge and attention components of PAD, some authors have started using different strategies and to engage student interest and attitude toward plants (Pany, 2014; Pany et al., 2019). This strategy has implications for educating students about the ways in which plants affect their everyday lives, especially in the context of botanical SSIs such as agriculture, biodiversity, and plant conservation (Amprazis & Papadopoulou, 2018; Hershey, 1993; Krishnan et al., 2019; Margulies et al., 2019).

Our paper suggests FBL as a potential starting point for helping students better understand the relevance of plants to their everyday lives. While FBL was originally designed to address PAD, it is important for us to understand the theoretical components and markers that make up FBL before exploring the relationship between PAD and FBL.
This paper contributes to the literature surrounding PAD by suggesting a new approach to address all four components of PAD, and situating this approach theoretically and within student data to demonstrate what FBL is and how it can be observed.

FBL is not only relevant to the literature surrounding PAD, however. Because of the nature of FBL and because it incorporates decision-making about SSIs and botanical literacy, students who develop FBL can potentially improve their FSL and botanical literacy skills as well. Botanical literacy is often an overlooked skill in biological education and can help students become more well-rounded in their thinking regarding biological concepts (Uno, 2009). Developing the skills associated with FSL is important not only to education in general, but also to students’ ability to function within a scientifically literate populace (Laugksch, 2000).

Acknowledgments

We acknowledge the University Center for Biodiversity Research (CBio) for funding that allowed us to travel to UNL and collect data. We would also like to acknowledge Dr. Jenny Dauer and Dr. Brandi Sigmon for assisting us in collecting data. Finally, we would like to acknowledge Sarah Baker and Eman Yonis for their assistance in analyzing the data in this study.
Appendices

Appendix A.

*UNL Module Assessment* (used with permission from Dr. Jenny Dauer)

Name: _______________________________ Group: ______________ Instructor: __________ LA: ________

**STUDENT WORK GOES HERE:**

1. Define the issue:

<table>
<thead>
<tr>
<th>OPTIONS</th>
<th>Type your 1st option here</th>
<th>Type your 2nd option here</th>
<th>Type your 3rd option here</th>
<th>Type your 4th option here</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRITERIA</td>
<td>Metric: Performance score:</td>
<td>Metric: Performance score:</td>
<td>Metric: Performance score:</td>
<td>Metric: Performance score:</td>
</tr>
<tr>
<td>Type your 1st criteria here</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight:</td>
<td>Multiply the weight x the performance score in this cell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Weight:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type your 2nd criteria here</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Type your 3rd criteria here</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weighted performance score:</td>
<td>Sum up the weighted performance scores in this cell</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Information, Step 4: justification of assigning your performance scores:

Criteria 1:

Criteria 2:

Criteria 3:
6. Choice:

A) Choose an “option” based on the analysis undertaken.

B) Why do you think this is the best option?

C) What are the tradeoffs (positive and negative aspects) associated with the option you chose?

7. Review (Reflect on your own decision-making process using these steps):

A) Who are the stakeholders who are “winners” and “losers” if this option is implemented?

B) Some of the options are not necessarily mutually exclusive, and more than one could potentially be implemented at the same time. Are there other options (either the ones listed or other things that you can think of) that you would like to see implemented to help solve this problem?

C) Do you think your chosen option is viable to be currently implemented in our society, and would work effectively to resolve the issue? Why or why not?

D) Did working through the slow-thinking decision-making framework (7 steps) result in your thinking differently about the issue? How?

8. Assigning Resources Let’s say you have $10 million dollars to allocate towards any of these options for solving the problem. How would you allocate the money? Place
$ amounts on one or more option to indicate how you would spend this money (it can all go to one option or could be split among several options):

_____ **Status quo: gasoline and diesel are dominant** (corn ethanol is primary biofuel, biofuels are supposed to increase in volume over the next 20 years)

_____ **Support second generation biofuels (corn stover, sorghum, switchgrass etc)** (by increasing federal government spending on research and development or subsidies for these fuels)

_____ **Promote and subsidize electric cars and renewable energy** (homes and business would produce their own solar or wind energy to power vehicles)

_____ **Municipal solid waste to fuel** (research and development money to develop turning garbage into fuel)

_____ **Educate and motivate to drive less and fly less** (Effective approaches and incentives need to be determined.)

**9. Importance of issue -** Is this issue an important issue?
Rank the issue on a scale of 1 (not at all important) to 10 (one of the most important issues): __________ Why?

10. **Impact** - Is there anything you could do to impact this issue? What are some things you could do?

11. **Your Actions** - Do you think your actions regarding this issue will make a difference? Why or why not?
Appendix B.

UofM Essay Assignment

Real World Scenario 2 Paper

*to be completed individually, not with your group

10 points

Directions (1 point)

1. Reflect on the Real World Scenario discussion and decision you made with your group and write a 1-2 page response that includes answers to each of the questions below. This paper will not be graded as correct or incorrect (it contains your own thoughts and opinions). However, in order to get full credit for this assignment, your responses must demonstrate that you have meaningfully considered the questions and answers and put forth effort to reflect on the topics. Papers less than 1 full page will not receive full credit. Headings do not count toward the 1 page minimum.

2. Type your responses with double-spaced text in 12-point Times New Roman font, and one inch margins.

3. Be sure to include citations for any references you use.

4. Turn the paper in to the dropbox on eCourseware before class on November 19

Questions to answer (3 points each)
1. Provide a summary of your group discussion and the decision your group reached. Describe your process of reaching the decision and differences in opinion you had. How did the papers you read influence your decision?

2. Describe your own decision and how you reached it. Was your decision different from your group’s? Why or why not? What additional factors did you consider in your decision?

3. Reflect on the decision-making process. Do you feel you were able to make an informed decision? What other resources or information would you need to make a decision like this in a real scenario outside of class?
Appendix C.

Interview protocol

1. What factors may contribute to how you think about plants? Please elaborate on why you think so.
2. Explain what a plant mentor is and ask if they’ve had one. Did they help you learn about plants? How? Can you describe some experiences you’ve had with your plant mentor?
3. Do you have many memories of being around plants/nature as a kid? Were they pleasant? Can you describe them for me?
4. What is your relationship with plants and nature like now?
5. Is there anything that you think is boring about plants? What is boring about them? Why or why not?
6. Is there anything else relevant to your life’s experience with plants that you want to share with me? Why did you choose this experience to share?
7. Think about plants and their relationship to humans. Please think aloud and list as many instances as you can of ways in which humans and plants interact in everyday life.
8. Why did you choose these examples?
9. How important do you think plants are to the ecosystem? Why?
10. How important do you think plants are to humans? Why?
11. In what ways are plants important to humans? List as many as you can think of.
12. Why did you choose these examples?
13. What are biofuels?

14. Do you think biofuels are an important topic to understand and learn more about? Why or why not?

15. Do you think we as a society should switch to using more biofuels instead of fossil fuels like gasoline, oil, diesel, and coal?

16. Do you think we should use both?

17. Do you think we should use neither? What should we use instead? Please explain your reasoning.

18. Do you think biofuels are an important topic that everyone should understand? Why or why not?

19. What external factors affect your feelings about biofuels? (Examples include articles on the internet, media coverage, social media information, coursework in school, etc.)

20. What internal factors affect your feelings about biofuels? (Examples include personal values, personal experiences, experiences of people you know, personal opinions, and personal investment, etc.)

21. What other ideas about biofuels do you have?

22. Is there anything important you want others to know about biofuels?

23. Do you have any personal experiences that are relevant to your feelings about, and understanding of, biofuels?
Appendix D.

*Codes and frequencies for UNL module assessment decision rationales with examples.*

<table>
<thead>
<tr>
<th>Category of rationale</th>
<th>Frequency (Out of 255 total codes from 74 assignments)</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chosen despite negative outcomes</td>
<td>8</td>
<td>“While this option does have high negative affects to farmers and rural communities, it does have the best interest for the future of our planet if we wish to live here.”</td>
</tr>
<tr>
<td>Convenience</td>
<td>1</td>
<td>“I think this is the best option because people drive everyday so it would be better to continue doing what we usually do but improve the way we do it by changing from diesel and gasoline to renewable energy.”</td>
</tr>
</tbody>
</table>
Cost 9  “I think it is the best option because it would eliminate most greenhouse gas emissions if practiced by the majority of the population and the atmosphere might be slightly more manageable. There are many benefits to driving electric and as a whole, I believe this is the best and most efficient, cost effective option.”

Directly references 31  “I think this is the best option because of my personal values and what the research yield with an overall weighted performance score of 2.4.”

Economy 23  “If people started using more ethanol it would help rural communities grow economically and it helps lower emissions and the needed for oil.”

Farmers 29  “I believe this is the best option because it is sustainable, helps reduce CO2 emissions, and also helps farmers economically. It is the best fit option.”
Few drawbacks 1

“This option also has the potential to create thousands of jobs. For example, if a grid that was composed of 80 percent renewable electricity, then the manufacturing of electric cars would reduce manufacturing emissions by 25 percent, and then emissions could be reduced by 84 from driving the electric cars. Or implementing renewable energy like wind energy can potentially create 80,000 new jobs and increase farmer income by 1.2 billion dollars. Also there were little drawbacks from this option.”

Food v fuel 4

“I think this is the best option because it's not impacting the food vs fuel debate that much and the research that has so far been done on it is promising in helping to lower greenhouse emissions.”

Food/ landfill 1

“There is a plethora of choices in which we can use and we can even use the byproducts and waste from materials we use on a daily basis in order to make fuel. These choices can also help us solve other sociopolitical topics such as food waste and landfill waste in order to make fuel, because that is the material we would use to do so.”
<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freedom</td>
<td>1</td>
<td>“This option gives people the freedom to do what they want but also leaves them feeling good when they make a personal choice to do something good.”</td>
</tr>
<tr>
<td>Improve health</td>
<td>1</td>
<td>“I believe this is the best option because it would have the greatest impact on greenhouse gas emissions, improve health, and cheapest for everyone. The only downfall would be that farmers wouldn’t have as high of a demand for their crops but that doesn’t mean that they won’t have a demand at all.”</td>
</tr>
<tr>
<td>Income/Profit</td>
<td>5</td>
<td>“Because it is versatile to any criteria. Second generation biofuels can help rural economy and farmers when the funding for research is increased. It would not do best in promoting electric vehicles or motivating the public to drive and fly less. Farmers and rural communities will benefit by getting dual profits off of the crop and the crop’s waste because second generation biofuels only use waste of crops. For renewable energy, second generation biofuels would not have any impact in that.”</td>
</tr>
</tbody>
</table>
Jobs 8

“This is the best option because renewable energy still gives us the energy we need while reducing the amount of greenhouse gases in the atmosphere. Renewable energy also causes a tremendous amount of economic growth because of all the jobs created with the industry.”

Personal values 7

“Option D had the highest total weighted performance score. This means that it is the best option because the score takes into account both my personal values (criteria weight) and the predicted efficiency of the option based on research (performance score). I also think it is the best option because it is the most efficient at directly solving the problem of greenhouse gas emissions from fossil fuels.”

Rural communities 16

“I chose this option because it tied for the highest scoring option based on my criteria. The reason I chose this option over Option 4, even though they scored the same, is because it supported the economic benefit to farmers and rural communities more than Option 4.”
Second gen biofuel materials are useless (except for biofuels).

“I feel like it will be the most successful option out of the four. For this option you are renewing sources and making them valuable. Sources that would normally just be thrown away or blown in the wind, like corn cobs, wood, switchgrass, and other renewable sources.”

Scientific motivation

“Because it does not produce gas emissions which are bad for the environment.”

Soil

“I think this is the best option because we can’t just continue to use corn to make biofuel. We have to come up with another source of products to make into biofuels. If farmers only plant corn year after year they will eventually ruin the soil to where nothing will grow.”

Vague

“I believe that this option is the best option out of the four because it will help more people in many ways.”
Appendix E.

*Codes and frequencies for UofM essay rationales with examples.*

<table>
<thead>
<tr>
<th>Rationale Code</th>
<th>Frequency</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articles/class</td>
<td>16</td>
<td>“After much deliberation and filling out the table, we arrived at the conclusion that algae would be the best option based on our criteria. Our decision-making process was entirely based on our readings as we relied on them exclusively for information in this process.”</td>
</tr>
<tr>
<td>Availability</td>
<td>4</td>
<td>“I myself thought that the best solution was algae. One reason is that we would not be taking away from a person’s food source. Also the numbers for the effects of the environment, availability, and how easily it can be reproduced were similar so we gave most a three in each part.”</td>
</tr>
<tr>
<td>Car companies</td>
<td>2</td>
<td>“Originally, we tried to narrow down our options solely by considering amounts of ethanol and how increasing, decreasing, eliminating, or maintaining the same amount of corn ethanol would effect consumers, agriculture, the government, car companies, and the planet as a whole.”</td>
</tr>
<tr>
<td>Topic</td>
<td>Score</td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>Chosen despite</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>drawbacks</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“I reached the decision that using a non-edible biofuel would be better for the environment and more economically safe as well. Algae can grow in a variety of different places and would not interfere with food production in areas that require corn for more than ethanol. I understood that it would take time and money to kick start this process, but it would be better than solely using fossil fuels until we are completely out of them.”</td>
<td></td>
</tr>
<tr>
<td>Convenience</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Everyone in the group agreed that using algae as an energy source would be incredibly convenient and ecofriendly, so we all decided to make research and implementation of algae energy a high priority in our analysis.”</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Corn ethanol became our best solution because is it less damaging than fossil fuels, and is also cheaper.”</td>
<td></td>
</tr>
<tr>
<td>Domestic production</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Using 100% cellulosic ethanol was the most renewable and was the easiest to produce domestically without having significant damage on the environment.”</td>
<td></td>
</tr>
<tr>
<td>Easy to implement</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“I thought that algae was the best choice for many reasons. The first reason being the ease of implementation, it is less difficult to implement algae.”</td>
<td></td>
</tr>
</tbody>
</table>
Overall, we discussed the effects of ethanol and how we could possibly change what we use to better benefit both the earth and the economy. In the end, we decided that figuring out some way to do away with ethanol would work well, and finding some alternative for it that would still provide as much fuel as we need while also not being overly expensive or hard to produce.”

“I thought Algae might be a better alternative for more than one reason. It could improve productivity and reduce costs, which is fundamental to the widespread future availability of algae biofuels, which in return could be prolific. It also doesn’t cut into food supply.”

“The impact it would have on stakeholder is that the price of food, specifically corn, will drop which should result in an increasing stress on the farmers. This means that the government must also increase certain kind of taxation to supplement the earning loss.”

“I still thought that sugarcane was the best option and after we totaled the score and rationale it ended up being the best biofuel. I also considered the factors of harvesting system of sugarcane such as topping, height, cane variety, age of the crop, climate, soil etc.”
“Along with this implementation, we also had many other options that we agreed on, including starting more research towards the study of solar, wind, and algae-based energy methods. Also, in order to increase corn production to help assist the biofuel shortage, we mentioned giving a government incentive towards farmers in order to encourage them to grow more corn. This is the decision that our group made, compromising so that we could have an energy-effective, profitable, and ecofriendly option for gasoline available while we studied more long-term options.”

“My decision was the choice of corn ethanol, after looking more into it and seeing it was well backed and already in use my group members agreed with me in my decision making because, corn ethanol was already in use meaning we didn’t have to worry about it not working, then the price of corn ethanol was cheaper than gasoline the only thing was corn ethanol burned faster, but everything else helped me and my group side with corn ethanol being the right primary choice.”
<table>
<thead>
<tr>
<th>Jobs</th>
<th>3</th>
<th>“Our criteria for what make a good biofuel are renewability, affordability, environmental gain, whether it is a food source to others, and job opportunities generated from its production.”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large scale</td>
<td>4</td>
<td>“Using 100% corn ethanol provided an option that was cost effective, and would be somewhat easy for fuel providers to convert to, but was not renewable at a large scale. Using 100% cellulosic ethanol was the most renewable and was the easiest to produce domestically without having significant damage on the environment.”</td>
</tr>
<tr>
<td>Other modes of</td>
<td>1</td>
<td>“I thought the decreasing the automobile transportation would be the best option because there are always alternative options for getting places and people don’t necessarily need a car to get around.”</td>
</tr>
<tr>
<td>transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(cars not needed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>People affected</td>
<td>24</td>
<td>“The decision that we collectively came up with for maximum effectiveness was the idea of using another form of ethanol to replace corn ethanol. This decision seemed to have more benefits and less issues for the environment and stakeholders in comparison to the other options.”</td>
</tr>
</tbody>
</table>
“Growing up the son and grandson of two Georgia Tech engineers, I have had many conversations about fuel types over the course of my life. Ethanol is a very inefficient source of energy and actually requires more energy to produce than it can produce itself, not including the additional energy to produce the crops. According to Cornell agricultural professor David Pimentel, “producing ethanol actually creates a net energy loss. His research shows that a gallon of ethanol contains 77,000 BTUs of energy for engines to burn but requires 131,000 BTUs to process into usable fuel, not including additional BTUs burned from fossil fuel sources to power the farm equipment to grow the corn, and the barges, trains and trucks used to transport it to refineries and ultimately fueling stations.” Travelling to Georgia for a funeral I was able to purchase ethanol-free gasoline in Mississippi and was able to achieve 37mpg on my vehicle as opposed to my usual 31 for purely interstate travel.”

“As far as my personal opinion, I agree that this is the most effective option. Based on the analysis of our chart, it would be the most beneficial in regard to stopping the problem and solving the solution.”
“We know that humans are not able to always to depend on fossil fuels. Instead, there needs to be a substantial alternative. There are multiple ways to do this: electric cars, different biofuels, or less transportation. However, what is fact is that fossil fuels do a great deal of damage to the environment and a contributing factor to global warming. As a group, we all agreed that fossil fuels are not sufficient due to the fact it will run out within the next 20 to 25 years, so we tried to figure out the best alternative.”

“The third reason my group and I chose algae is because of its space requirement, algae does not require as much space as the other options.”

“Before even rating the options, I already knew that using other fuel sources would be the best option. I came to this conclusion because things like switchgrass and algae grow fast and easy and do not interfere with food sources needed.”

“For criteria we all agreed, although I at least don’t think I agreed with the order. We wrote price, environmental impact, space used, economic impact in both foreign and national countries, and time frame. Time frame meaning how long it would take to fully implement.
We all agreed on possible solutions like, switch grass and other by-products, algae, electric energy, and corn ethanol.”

“As far as my personal opinion, I agree that this is the most effective option. Based on the analysis of our chart, it would be the most beneficial in regard to stopping the problem and solving the solution.”


**Appendix F.**

*Codes and frequencies for UNL and UofM interview rationales with examples.*

<table>
<thead>
<tr>
<th>Rationale Code</th>
<th>UNL Frequency</th>
<th>UofM Frequency</th>
<th>Total Frequency</th>
<th>Example Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articles/news</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>“In class this past semester, we’ve learned a lot about them. And like I said, articles being sent to me, just by friends and whatnot. So I just get an influx. I’ve gotten, especially in the last, just, probably, year, I’ve gotten an influx of information about them.”</td>
</tr>
<tr>
<td>Class</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>“External, this class has really done a lot in terms of changing my information knowledge level, and introducing me to new things like the algae. I’d heard about the cornfields, never heard about the algae stuff before now. So that definitely... It’s doing a lot in terms of just kind of nudging me in different directions, opening my eyes as it were.”</td>
</tr>
</tbody>
</table>
“So I’d say that an internal factor would be coming from a farming family. So if I think that it’s going to raise the prices for everything or even a farmer that has to rent out land, if there’s more biofuels being made, then there’d be bigger companies, so the price of land to rent is going to cost more. That would be a negative effect to farmers that have to rent their land.”

“I think for both of them I can answer the socioeconomic level. Financial stability is a big thing, and right now we’re paying near my house, it’s $2.23 a gallon for gas. Yeah, and my hometown back in Nashville, it’s $2.67. I’m looking at it from the external view of financial stability. In my internal version is also financial stability, and that plays a big factor in it for me is to be able to have the funding for it, to be able to even though I’m a big supporter of biofuels, how much is it going to cost me in the long run? That’s a big thing for me.”
“Well, I think that a lot of people don’t think about what taking away fossil fuels will do to even the world economy.”

“I know the U.S. is in debt because we buy a lot of oil from someone. I want to say Iran, I want to say that. And that put us a lot in debt. So, that’s why I feel we shouldn’t put ourselves more in debt. So, we should find alternatives. Not to mention that’s pretty bad for the environment to keep using fossil fuels. So, maybe start using other kinds.”

“Okay, so internally, I would say what impacts how I feel about biofuels from a cultural standpoint would probably be like the importance of just like being very modest with what you use in a way, and not trying to excessively use too much or too little than what you need in that moment. I feel like that makes me look at biofuels in a positive way because it’s doesn’t seem like it is causing too much harm to the environment.”
<table>
<thead>
<tr>
<th>Category</th>
<th>Start</th>
<th>End</th>
<th>Word Count</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opinions (personal and others')</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>“I guess my own opinions and the opinions of others, because you’ve got to take account and see the other perspective to get a whole picture.”</td>
</tr>
<tr>
<td>Personal belief system</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>“Yeah, I feel like just my personal beliefs and opinions that we should really help the planet, since we’ve done a lot to damage it in the past years.”</td>
</tr>
<tr>
<td>Personal motivations</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>“Probably just, I know a lot of people that work in the oil fields and that a lot of my family or coworkers that work in mines so just that it like that affects their jobs. So that would make me feel negatively about it.”</td>
</tr>
</tbody>
</table>
| Politics                      | 0     | 2   | 2          | “I mean, obviously... then we’re going to get into a whole political thing. I’m a history major, you don’t really want to get into it with me. Either side always tends to see the other one as the enemy, but that’s really the wrong way to look at it. And I mean just because you
may not agree with everything on the other side, then that doesn’t mean you can’t see a point in something that they have. For example, there are a lot of policies on the left that I do not agree with. But I definitely wouldn’t say that environmental awareness is the biggest concern of our country right now by any stretch.”

“Yeah, I feel like we do need to take better care of the planet, and I do feel that climate change is an actual issue. Any steps that we can take just to reduce the impact that we have on the world would be good.”

“So both internally and externally, it’s just how much knowledge I have about the topic. At first when I... The first time I heard about GMOs and everything, it was probably, I guess from, it was articles and YouTube videos where a lot of the science that’s based around it is a pseudoscience. And I didn’t realize that there was a thing such as pseudoscience. I just figured that the scientific process or the
experimenting with something and then seeing how that goes. And then, I figured that that was the way a lot of the things were brought about and how a lot of people came to that I guess, conclusion. I didn’t realize that causality and correlation or two different things and just because whatever was afflicting you at first just so happened to stop around the time that you ate that plant or you decided to put that on your skin, doesn’t necessarily mean that that is what happened or that carried you.”

“Because people as a whole have the really issue with change, and so you couldn’t just switch it immediately, because people will, one, resist it, just based on their own intuitions of, ‘We can’t do something new. We just can’t do it. I’m safe. I’m comfortable with what we’re doing.’”
“I would say social media does have an impact because when I do get on there, I see a lot of memes or things that project this idea of, ‘you only live once, it doesn’t matter what you kind of use.’ But, then again, it’s like, that’s not what we all should be thinking about, just from that side, and also see what’s on the other side.”

“Just because if we do make the shift you should know what you’re consuming. I don’t know, I just think it’s good to be current.”

“Because it keeps options open and the conversation open, because you don’t want to be close minded and be like, ‘I don’t want to hear your side because it’s wrong. I think it’s wrong.’ Because then it alternately gets you to come together and look for solutions for problems. If we’re running out of fossil fuels, how can we do other substitutes and different methods to get more fossil fuels, maybe?”
References


Parsley, K.M. Daigle, B.J., & Sabel, J.L. Development and Validation of the Plant Awareness Disparity Index to Assess Undergraduate Levels of Plant Awareness Disparity.


Strgar, J. (2007). Increasing the interest of students in plants. *Journal of Biological*


CHAPTER 5: HOW DECISION MAKING ABOUT A BOTANICAL
SOCIOSCIENTIFIC ISSUE CHANGES OVER THE COURSE OF A DECISION-
MAKING INTERVENTION

Introduction

Scientific literacy is the goal of most Western science education programs (Liu et al., 2010). However, scientific literacy is an overly-simplistic term. It has previously been defined as what the public should know about science, but that definition often hides many different meanings and interpretations because what the public should know about science will differ based upon who one asks and who one considers to be the public (Laugksch, 2000). One conceptualization of scientific literacy was developed by Zeidler and Keefer (2003) and is known as functional scientific literacy. Zeidler and Keefer (2003) explored science literacy in the context of socioscientific issues (SSIs), cognitive development, and moral reasoning. Socioscientific issues are potentially controversial scientific topics that are composed of both scientific and social aspects which impact society (Zeidler & Nichols, 2009). Students who are able to carefully consider SSIs and make reflective decisions may be said to have acquired a degree of functional scientific literacy.

There are two known systems that humans use for making decisions: system one (fast-thinking) and system two (slow-thinking) (Kahneman, 2011). System one operates automatically and very quickly, usually relying on heuristics and biases that are often inaccurate and result in errors in decision-making (Kahneman, 2011). System two is responsible for effortful thought and concentration, often resulting in decisions that are more logical and rational (Kahneman, 2011). Much of the field of decision-making as it
relates to science education has focused on influencing students to get them to switch from fast thinking (system one) to slow thinking (system two) when faced with making decisions about SSIs (Alred & Dauer, 2020; Dauer et al., 2017; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019). This is particularly challenging because SSIs are often controversial, which means students often respond emotionally toward them. Decision-making regarding SSIs is a primary way that students are able to demonstrate functional scientific literacy, and because of this, the goal of many science education studies is to determine what variables can help instructors predict and influence student decision-making.

Botanical SSIs are specifically related to real-world issues regarding plants such as GMOs, plant conservation, and biofuels. To understand how students make decisions regarding botanical SSIs, I first developed a conceptual framework to integrate the aspects of botanical literacy, decision-making and socioscientific issues. The new framework is referred to as functional botanical literacy (FBL; Chapter 3; Parsley et al., in review). Here, I focus on how FBL differs in varying contexts, while other current and future studies will continue to explore other parts of this framework (Chapter 3; Parsley et al., in review; Chapter 4; Parsley & Sabel, in progress).

In order to observe how FBL can change over time, I compared decision-making across assignments within a decision-making intervention at UofM. To this end, I developed the following research questions:

1. How does decision-making change over the course of a decision-making intervention in a general biology course?
2. How do student rationales behind their decisions change over the course of a decision-making intervention in a general biology course?

**Conceptual Framework**

*Figure 1*. Functional botanical literacy diagram. Functional botanical literacy (FBL) is comprised of two main components: functional scientific literacy and botanical literacy. These two components merge together to become FBL in the diagram. FSL is comprised of a combination of decision-making skills and socioscientific issues (SSIs). Within FBL, botanical literacy is combined with botanical SSIs which is reflected by the plus sign between the two components. The use of botanical literacy in combination with botanical SSIs is what sets FBL apart from FSL.
Functional Scientific Literacy

Functional scientific literacy (FSL) is a competent form of scientific literacy, meaning that it is an intermediate level of literacy between mastery and non-mastery (Laugksch, 2000). An intermediate form of mastery like functional scientific literacy is appropriate for undergraduate students, as they are not yet expected to be masters in scientific literacy, but they are expected to be above the beginner level and continuing to develop this literacy. Intermediate forms of science literacy typically require students to perform a specific function to demonstrate their literacy (Laugksch, 2000; Zeidler et al., 2005). In the case of FSL, the functional goal is to make sound, scientifically-informed decisions about socioscientific issues (SSIs). SSIs are a fundamental dimension of scientific literacy, and decision-making about an SSI is a common functional goal across many forms of science literacy (e.g. Alred & Dauer, 2020; Dauer et al., 2017; Roberts & Bybee, 2014; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019).

Botanical Literacy

Botanical literacy is defined as what students should know about plants, and is a subset of biological literacy (and, by extension, a subset of scientific literacy) (Uno, 2009). Previous research states that botanical illiteracy exists mainly due to a lack of student interest in plants, low exposure to plants throughout school years, and because students lack intellectual curiosity and rigor despite being technologically advanced (Uno, 2009). This characterization of botanical literacy is currently the only known definition of the term, making further investigation and description critical. Uno (2009) suggests that simply teaching botanical content is not the most effective way to combat
botanical illiteracy. Instead, educators should prioritize using plants to teach major biological concepts, using engaging teaching methods, and utilizing plants to develop critical thinking skills. Unfortunately, students are not inherently interested in botanical content, and PAD has a powerful negative effect on the way students think and learn about plants (Parsley, 2020; Wandersee & Schussler, 1999; Uno, 2009).

Uno (1994) noted that teachers lack the flexibility they need to move beyond strict educational guidelines in K-12 environments, and this can contribute to botanical illiteracy as well. This is especially true if botanical examples are not used for over-arching biological concepts. Unfortunately, plants tend to be taught separately and in a way that does not engage student interest (Uno, 1994). The disconnect between the nature of botanical literacy and the teaching of botanical content itself is only contributing to the disparity among students who are and are not interested in plants, thereby contributing to PAD (Uno, 2009). Students who are naturally interested in plants will continue to seek them out, while those who are not will continue to avoid them at all costs (Uno, 2009). In order to mitigate this problem, educators need to find ways to engage all students’ interest in plants and use their interest as a segue into teaching botanical content that is useful and relevant to students’ lives (Uno, 2009).

**Functional Botanical Literacy**

Functional botanical literacy (FBL) is defined as the ability to make sound, scientifically-informed decisions about botanical socioscientific issues (SSIs). It is comprised of two main concepts: functional scientific literacy (FSL) and botanical literacy. FSL is defined as the ability to make sound, scientifically-informed decisions
about SSIs (Laugksch, 2000). In the case of functional botanical literacy (FBL), the function that students will perform is making a decision about a botanical socioscientific issue (SSI). This specific decision-making exercise in a socioscientific context such as biofuels is also important because the botanical SSI students will make a decision about is designed to increase their interest in, and improve their attitudes toward, plants (Chapter 3; Parsley et al., In review).

Overall, functional scientific literacy is incredibly important to FBL because it forms the theoretical and functional basis for the skills students need to be considered functionally botanically literate. Because it is concerned with decision-making in the context of SSIs, FSL is comprised of both SSIs and decision-making skills. The other main component of FBL, botanical literacy, is simply defined as what students should know about plants (Uno, 2009). In this framework, we have combined botanical SSIs and botanical literacy because the combination of botanical SSIs and botanical literacy is what sets FBL apart from FSL.

Given that FSL shares many similarities with FBL, it is important to delineate between these two concepts. FBL differs from FSL in that 1) it specifically utilizes botanical SSIs only, and 2) it incorporates botanical literacy, and thus, is only appropriate to be used in situations where efforts are being made to improve botanical education in some way. While it may also be of use in other botanical education and literacy contexts, we designed FBL primarily to address plant awareness disparity (PAD).

The development of FBL to address PAD stems from a hypothesis that the botanical SSIs in FBL could appeal to student interest in and attitudes toward plants,
potentially laying the groundwork for addressing PAD from a different starting point.

PAD is made up of four components: attention, attitude, knowledge, and relative interest (Parsley, 2020; Wandersee & Schussler, 1999). *Attention* is the idea that students do not notice plants in their environment, and this component forms the basis for the original definition of PAD. *Attitude* refers to the phenomenon wherein students do not like plants, and do not enjoy learning about them. *Knowledge* is made up of students’ understanding (or lack thereof) about plants, particularly knowledge of the importance of plants. *Relative interest* refers to the fact that students tend to demonstrate more interest in animals than they do in plants. Previous interventions for PAD tend to target or measure the attention and knowledge components over the attitude and relative interest components (e.g., Fancovicova & Prokop, 2011; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman 2006; Ward, Clarke, & Horton, 2014). However, FBL is unique in that it instead targets student interest and attitudes through the use of botanical SSIs.

However, it is important to note that FBL could be used in other botanical education contexts beyond PAD. While this is certainly a possibility for future studies, the use of FBL in other contexts is beyond the scope of this work, as we are primarily concerned with the development and characterization of FBL. It is also important to note that while FBL was designed to address PAD, this work is prioritizing the development and characterization of FBL rather than exploring potential relationships between FBL and PAD. The reasoning for this is that, while we know what PAD is and how it is characterized, we do not have this information for FBL. Therefore, it is important to lay
the theoretical groundwork for FBL before exploring how FBL may affect PAD (and vice versa).

Despite the research conducted and the development of engaging ideas about how to improve botany education, researchers and educators still need a way to help students understand plants’ relevance to everyday life and their importance to humans. Our research contributes a potential solution to this problem with the development of FBL. In this paper, we will explore how decisions and the rationales behind them can be used as markers for FBL, and how these markers change over time during a botanical SSIs unit with a focus on decision-making in a general biology course.

**Methods**

**Course Context**

The University of Memphis (UofM) is a large urban university in the midsouth. The course we studied at UofM includes primarily non-STEM majors and is one option for the biology general education requirement of all students at the university (N=119). The course is a traditional non-majors biology course that covers cell structure and function, genetics, and evolution topics. Each unit also includes a Real World Scenario in which students must consider how the science content fits into situations they may encounter outside of the classroom (Sabel & Sorin, in review). In particular, as an addition to the photosynthesis content, it includes a biofuels section modeled after the biofuels unit developed at UNL (Chapter 4; Parsley et al., in progress). At UofM, students spend three days on the biofuels content and decision-making.
The UNL course utilizes a highly scaffolded approach so that a lot of background information is presented along with the decision-making framework. Students are given the criteria and options in each decision and asked to weigh those criteria based on their level of importance to each student. Options are assigned to students for them to research and are then weighted based on how well they address each criterion. In the biofuels unit, students are presented with four options and four criteria but asked to research only two of these options and criteria (see Appendix A). The instructors present students with information on the other two options. As the course progresses, they learn how to research and weigh all four options against all four criteria in the unit at the end of the course. Additionally, the very beginning of the course covers fast and slow thinking, the decision-making framework that students will use all semester, what criteria are and how to weigh them, as well as what options are and how to research and evaluate them. There is also a great deal of instruction focused on how to find and evaluate different types of scientific literature and information as part of the research process associated with finding options for solutions.

None of this scaffolding exists in the UofM course, as it is focused on biology content rather than on decision-making. There is only one decision-making activity completed and it is during the biofuels unit that is associated with photosynthesis class content. Fast and slow thinking is covered in the course, along with information about criteria, options, and the decision-making framework that is also present at UNL (Kahneman, 2011). Students are asked to come up with all of their own options and criteria and weigh them. However, they are provided with articles about corn ethanol and its benefits and drawbacks to help them consider a wide array of variables in their
decisions. Students also watched a video during the first day of the biofuels unit about algae and how it can be used as a biofuel. Additionally, the textbook used at UofM has a focus on algae as biofuel for the photosynthesis chapter.

**Data Collection**

I collected artifacts from the U of M course that included: a quick decision activity created by the course instructor, group decisions that are a modified version of what is used at UNL, and student essays which are an extended version of the quick decision activity that are done by individual students instead of groups. The quick decision was completed by the students individually on the first day of the biofuels unit, and included the questions, “1. Should we use corn ethanol as a fuel source? To what extent? Explain your reasoning,” “2. Should we replace corn ethanol with another biofuel? To what extent? Explain your reasoning,” and, “3. What biofuel has the most potential (considering all the advantages and disadvantages of each)? Explain your reasoning,” (see Appendix B.) The group decisions were structured and resemble the module assessment decision-making activity in the UNL course but are more flexible and allow students to brainstorm their own options and list their own criteria rather than providing them (see Appendix C). Examples of student-generated options include, “Only using corn ethanol,” “100% algae ethanol,” “Continuing current system,” and, “Make more vehicles diesel.” Examples of student-generated criteria include, “The environment is something to consider and protect,” “Cost (government and consumers),” “Animals (biodiversity),” and, “Greenhouse gas emissions.”
Students at UofM were also asked to score these options for how well they satisfied the criteria in the same manner as they are at UNL. These criteria scores were then used to help students decide upon which option was the best fit regarding what type of fuel we should use in the U.S. Additionally, students were not required to do research about how well their options satisfy their criteria, but they are asked to choose one option and explain why they decided upon this option as the solution. They are also presented with three articles about corn ethanol for the activity, as resources they can evaluate for scientific information on this particular type of biofuel. The activity took place on the last day of the biofuels unit. Finally, the student essays were an extended version of the group decision activity with information on whether or not the student agreed or disagreed with their group (see Appendix D). These were assigned at the end of the photosynthesis portion of the course.

Data Analysis

To address the first research question, the undergraduate students I supervised evaluated the artifact data from UofM. They categorized each decision from question three in the quick decision assignment and the last portion of the group decision assignment using categorical content analysis and generated frequency counts which they passed on to me. I evaluated the decision essays to look for all the decisions made in each one. Several students made more than one decision in their essay, so I included all decisions in order to best represent how students’ decision-making changed over time. I then coded the decisions based on what biofuels students chose and generated frequency counts for these codes. These categories were very specific, so I used categorical content analysis to collapse them into more general groups in order to make it easier to compare
the decisions from the first assignment (quick decisions) with the second (group decisions) and third (decision essays) assignments (see Tables 1 and 2; Saldana, 2013). I then generated frequency counts across all three assignments for each category.

To determine whether the decisions made in each assignment indicated FBL, I observed each decision category to determine whether it was scientifically valid or not. In this case, scientific validity would be demonstrated by any decision that does not include fossil fuels, as students were taught about the detrimental effects fossil fuels have on the environment. Given that the entire purpose of the biofuels unit was to educate students about this topic and what alternatives can be found using biofuels, I determined that as long as students chose a form of energy that did not include fossil fuels, this would demonstrate some level of FBL. Because the goal of FBL is to enable students to make scientifically-informed decisions about botanical SSIs, if they choose fossil fuels, they are choosing a decision that is not informed by science in regards to the damage being done to the environment via fossil fuels.

To address the second research question, I evaluated all three decision-making assignments to look for rationales behind student decisions. I then used categorical content analysis to combine similar answers into a more general categories (Saldana, 2013). I then completed frequency counts for each rationale category to observe trends in how often each answer category occurred across the assignments.

For the purpose of this study, any rationale that incorporates science of some kind was also considered a marker of FBL, because the overall goal of FBL is for students to make scientifically-informed decisions regarding botanical SSIs such as biofuels.
Because this study is concerned with how these markers change over time, I did not separate the scientifically-informed answers into further categories. Instead, I opted to focus on the scientific validity of the decisions themselves, and how often students cited science in their rationales, so as to better elucidate the overall trend of how FBL markers change over time. Additionally, I wanted to determine what rationales besides science students use to support their decisions, so as to better understand what challenges students face during these decision-making activities (and by extension, make better recommendations for instructors regarding how to avoid or address these challenges).

Results

Comparing Decisions Across All Three Assignments at UofM

In the first research question, I asked, “How does decision-making change over the course of a decision-making intervention in a general biology course?”, I found that, across all three assignments at the UofM, students chose algae as the biofuel they would pick to replace fossil fuels most frequently (see Tables 1 and 2). Some examples of decisions that were categorized as algae in the quick decision assignment include, “The algae, because we are able to produce more than land plants,” “I think maybe algae has the most potential because of the natural oils but that doesn't promise that its less expensive,” and, “I'm really down for the algae. It's relatively easy and EXTREMELY fast rate of growth would work well, as well as the fact it grows basically everywhere.”

Some examples of decisions that were categorized as algae in the group decision assignment include, “We should replace corn ethanol with another form of ethanol such as algae,” “After discussing pros and cons algae was more prolific and highly rated,” and,
“100% algae because we already have support from major companies ethanol and wouldn't affect us bad as other options.” Some examples of decisions that were categorized as algae in the essay decision assignment include, “My own decision matched the consensus of my group as I decided algae was the best means of production overall,” “Algae are a great alternative,” and, “In conclusion, we concluded that the best method to use was to use algae as a biofuel because it meets all the criteria and honestly just seemed like the better option.”

I considered this decision to be scientifically valid as algae is a viable alternative fuel that would help alleviate the negative impact of fossil fuels upon the environment. It is noteworthy that across all three assignments, the top decision was a scientifically valid one and indicated some level of FBL, as this course is a general biology course with only one decision-making intervention. Algae was the top choice even during the quick decision at the beginning of the intervention, which only took place on the first day of the biofuels unit.

Following algae, corn ethanol was the most popular decision during the quick and essay decision activities. Some example quick decisions that were assigned to the corn ethanol category include, “I think that corn ethanol has the most potential because we have been dependent on it for so long,” “I believe corn has the most potential because they are already so fast along with it,” and, “Corn because we use that the most and are trying to use the whole plant instead of just the kernels.” Some example essay decisions that were assigned to the corn ethanol category include, “As a group we scored the option of only using corn ethanol as the best solution, for right now,” “The final decision was to
support the use of corn ethanol while researchers find the right way of producing fuel,” and, “My group and I decided that corn ethanol seemed to be the most rational to use.”

I also considered this decision to be scientifically valid. As students pointed out in several of their answers, corn ethanol has been used to help alleviate the effects of fossil fuels on climate change for years. Although it is not as efficient as other options are, it is nonetheless valid as it is not considered a fossil fuel, and many students chose it as their preferred alternative to fossil fuels in the quick and essay decisions.

However, for the group decisions, the second most frequent decision was biofuels in general. Some example decisions that were assigned to the general biofuels category include, “My overall thoughts on Biofuels and corn being used as a substrate to produce ethanol. I originally thought it was a good idea but after my research I would have to disagree due to the percentages. I chose the number rating based off of the options to be and how they could work together as an overall situation,” and, “We decided to promote the use of biofuels (100%) over fossil fuels.”

I considered this, too, to be a scientifically valid decision. It would have been preferable for students to specify which biofuel they felt was the best choice, but biofuels as a whole are more scientifically valid a decision than fossil fuels due to their ability to lessen negative impacts upon the environment. It is noteworthy, however, that more students chose a less specific answer during the group decision, as this is not also reflected in the quick and essay decision assignments.

Lastly, a tendency to be indecisive was also present across all three decisions, as students often were unable to decide between two decisions or often tried to combine two
decisions into one answer. However, the number of students who were indecisive regarding which biofuel they would choose decreased across assignments. This could indicate that as they progressed through the biofuels unit, students became more decisive about biofuels because their knowledge on the subject increased. It could also indicate that students were more apt to choose an answer such as the generic biofuels answer, as there was one more group who chose that over being completely indecisive in the group assignment. This points to a trend where students begin to clearly favor biofuels over fossil fuels, but still have trouble deciding upon which biofuel they would choose as the replacement for fossil fuels.

Because students were being indecisive rather than choosing a specific decision, it is difficult for me to say if this is scientifically valid or not. Students were neither choosing fossil fuels nor biofuels in these situations, and as such, this choice cannot be characterized as valid or not valid. It is encouraging, however, that students became less indecisive over the course of the biofuels unit.
Table 1.

*Class decision frequencies across all three assignments.*

<table>
<thead>
<tr>
<th>Decision Categories</th>
<th>Frequency of Category in Quick Decision Assignment (out of 55)</th>
<th>Frequency of Category in Group Decision Assignment (out of 21)</th>
<th>Frequency of Category in Essay Decision Assignment (out of 121)</th>
<th>Total Frequency of Category (out of 195)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algae</td>
<td>37 (67.27%)</td>
<td>4 (19.05%)</td>
<td>25 (20.66%)</td>
<td>66 (33.85%)</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>1 (1.82%)</td>
<td>0 (0.00%)</td>
<td>1 (0.83%)</td>
<td>2 (1.03%)</td>
</tr>
<tr>
<td>Non-biofuel clean energy</td>
<td>1 (1.82%)</td>
<td>2 (9.52%)</td>
<td>11 (9.09%)</td>
<td>13 (6.67%)</td>
</tr>
<tr>
<td>Completely indecisive</td>
<td>3 (5.45%)</td>
<td>2 (9.52%)</td>
<td>1 (0.83%)</td>
<td>6 (3.08%)</td>
</tr>
<tr>
<td>Corn/corn ethanol</td>
<td>7 (12.73%)</td>
<td>2 (9.52%)</td>
<td>24 (19.83%)</td>
<td>33 (16.92%)</td>
</tr>
<tr>
<td>Biofuels non-specific</td>
<td>1 (1.82%)</td>
<td>3 (14.29)</td>
<td>11 (9.09%)</td>
<td>14 (7.18%)</td>
</tr>
<tr>
<td>Mixes</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>6 (4.96%)</td>
<td>6 (3.08%)</td>
</tr>
<tr>
<td>Category</td>
<td>Sugarcane</td>
<td>Switchgrass</td>
<td>Cellulosic ethanol</td>
<td>Other ethanol (not corn)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------</td>
<td>-------------</td>
<td>--------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td></td>
<td>1 (1.82%)</td>
<td>1 (4.76%)</td>
<td>5 (4.13%)</td>
<td>7 (3.59)</td>
</tr>
<tr>
<td></td>
<td>1 (1.82%)</td>
<td>1 (4.76%)</td>
<td>8 (6.61%)</td>
<td>10 (5.13%)</td>
</tr>
<tr>
<td></td>
<td>0 (0.00%)</td>
<td>1 (4.76%)</td>
<td>8 (6.61%)</td>
<td>9 (4.62%)</td>
</tr>
<tr>
<td>Other ethanol</td>
<td>0 (0.00%)</td>
<td>1 (4.76%)</td>
<td>7 (5.79)</td>
<td>8 (4.10%)</td>
</tr>
<tr>
<td>(not corn)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educate</td>
<td>0 (0.00%)</td>
<td>1 (4.76%)</td>
<td>3 (2.48%)</td>
<td>4 (2.05%)</td>
</tr>
<tr>
<td>Transitions</td>
<td>0 (0.00%)</td>
<td>2 (9.52%)</td>
<td>6 (4.96%)</td>
<td>8 (4.10%)</td>
</tr>
<tr>
<td>Second generation biofuels</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>1 (0.83%)</td>
<td>1 (0.51%)</td>
</tr>
<tr>
<td>Fossil fuels</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>3 (2.48%)</td>
<td>3 (1.54%)</td>
</tr>
<tr>
<td>Corn stover</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>1 (0.83%)</td>
<td>1 (0.51%)</td>
</tr>
<tr>
<td>Palm oil</td>
<td>2 (3.64%)</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>2 (1.03%)</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1 (1.82%)</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>1 (0.51%)</td>
</tr>
<tr>
<td>Fibrous non food plants</td>
<td>0 (0.00%)</td>
<td>1 (4.76%)</td>
<td>0 (0.00%)</td>
<td>1 (0.51%)</td>
</tr>
<tr>
<td>Most Popular Decision Categories</td>
<td>Quick Decision Assignment</td>
<td>Group Decision Assignment</td>
<td>Essay Decision Assignment</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
<td></td>
</tr>
<tr>
<td>Algae</td>
<td>“Algae, because it is always growing and someone doesn't have to farm it.”</td>
<td>“After discussing pro's and con's algae was more prolific and highly rated.”</td>
<td>“My own decision matched the consensus of my group as I decided algae was the best means of production overall.”</td>
<td></td>
</tr>
<tr>
<td>Corn/Corn ethanol</td>
<td>“Corn because we use that the most and are trying to use the familiarity we can keep producing corn, benefits other business”</td>
<td>“Keeping it the same (10%) -&gt;”</td>
<td>“We concluded that corn ethanol had the highest score and seemed the most”</td>
<td></td>
</tr>
</tbody>
</table>
whole plant instead of just the kernels.”

Biofuels (non-specific)  “I believe they all have the same amount of potential. It really depends on how much is needed? Can we keep up with the supply and demand, and how much will it cost. My biggest concern is not being able to supply enough food because we've used it for gas.”

Non-biofuels clean energy  “I'd say solar, because it is less likely we'd ever be without UV rays coming down to Earth only.

industries, and it currently works.”

“We believe that there are more and better options than using corn ethanol. We listed different options that would be more efficient and better for the environment.”

“My decision was the same as the group when it came to the fact of finding another solution. On my own I wasn’t necessarily concerned with which crop would be used.”

“Garbage; does not compete w/ food, lowers emissions from fossil fuels, prices are lower.

“Overall, the conclusion we came to was that
advantage would be for dark areas which aren't supported by rays."

using waste to create fuels, and production of ethanol exclusively used for health purpose.”

we needed to find a different source of fuel that’d work well, and we settled on either a mix of ethanol and something else until we can phase ethanol out entirely, or switching entirely to a cleaner solution, such as hydrokinetic energy, solar energy, or wind energy.”
Comparing Rationales Across All Three Assignments at UofM

In the second research question, I asked, “How do student rationales behind their decisions change over the course of a decision-making intervention in a general biology course?” I found that scientific reasons were the most common across all three assignments, and students often cited examples such as climate change, greenhouse gas emissions, pollution, renewability and sustainability, etc. For example, some answers that fell into the scientific reasons category in the quick decision assignment were, “Algae because it is safer for the environment as far as what it is putting out into the air, easily replenishable,” “Algae is the biofuel with the most potential because it is non-edible and doesn’t require fermentation,” and, “Algae. The main reasons because it can produce much more energy per acre than other crops… It is very accessible in that you can grow it anywhere due to its variety.”

Some examples of answers that were included in the scientific reasons category during the group decision assignment include, “We believe that there are more and better options than using corn ethanol. We listed different options that would be more efficient and better for the environment,” “Use switch grass or algae because it grows fast, emits less CO2, and does not interfere with food supply,” and, “100% cellulosic (preferably non-edible) ethanol. It is renewable, and it is already abundant in our ecosystem.” Finally, some examples, of answers from the essay decision assignment that fell into the scientific reasons category include, “Using 100% cellulosic ethanol was the most renewable and was the easiest to produce domestically without having significant damage on the environment,” “I came to this conclusion because greenhouse gas
emissions could be lowered significantly with this method,” and, “It would have a positive impact on the environment.”

Over the course of the unit and across all three assignments, the proportion of scientifically-informed rationales increased (see Table 3). This could indicate that students' FBL was also increasing as they progressed through the biofuels unit. This combined with the result that the top two decisions across each assignment were also scientifically valid are indicators that students may have been developing higher levels of FBL throughout the unit.

However, following scientific reasons, the second most common rationales varied across each assignment. The second most common rationale category for the quick decisions was speed/grow fast. Some examples of answers that fell into this category included, “Algae is the biofuel that has the most potential because it grows rapidly and we will always be able to use it,” “I'm really down for the algae. It's relatively easy and EXTREMELY fast rate of growth would work well, as well as the fact it grows basically everywhere,” and, “Algae has the most potential because it can be grown the quickest and doesn't interfere with food sources or anything else.”

Students were exposed to algae as a biofuel via reading their textbook and a video shown during the first day of the biofuels unit. The video emphasized how quickly algae can be processed and used as a biofuel, and students emphasized this same characteristic during their quick decision activity. The quick decision activity and the video about algae both took place on the first day of the biofuels unit, so the video likely had an effect on how the students were answering the assignment. As such, this rationale is not
scientifically informed in the sense that it does not emphasize the scientific validity of using algae to avoid greenhouse gas emissions associated with fossil fuels. However, it is still noteworthy that students appear to have engaged with the material strongly on the first day of the unit.

The second most common rationale category for the group decision-making assignment was referencing criteria from the assignment itself. Some examples of answers that fell into this category include, “Using our table, this decision had the highest total because it is most beneficial in causing less problems and more solutions,” “Using non-food and other fibrous plants had the highest score and is most beneficial,” and, “Using pure ethanol because it has the highest score based on the criteria.”

This finding is noteworthy in that it indicates the assignment itself had an effect on how students made their decisions. Students cited the assignment as well as the criteria and options within it as the rationale behind their decision, which would indicate that the intervention did impact their decision-making to some extent. While this is a useful piece of information, these rationales cannot be considered scientifically informed because they do not cite science specifically, and many of the criteria students included in their assignment were topics other than science (e.g., cost, speed of growth, etc.).

The second most common rationale category for the essay assignment was cost. Some examples of answers that fell into this category include, “The second reason my group and I chose algae is because of the cost, algae is less expensive than the other options,” “I thought Algae might be a better alternative for more than one reason. It could improve productivity and reduce costs, which is fundamental to the widespread future
availability of algae biofuels, which in return could be prolific,” and, “Algae cost was the highest compared to the rest, and sugarcane and corn ethanol was the lowest.”

In this case as well, cost is not considered a scientifically-informed rationale. However, it is notable that students were concerned with cost, as this was also discussed within the corn ethanol articles and the algae video that students received during the biofuels unit. So while the rationale of lowering costs may not be scientific in and of itself, the information for what biofuels cost did come from information presented within the course.

Table 3.

Class rationale frequencies across all three assignments.

<table>
<thead>
<tr>
<th>Rationale Category</th>
<th>Frequency of Category in Quick Decision Assignment (out of 55)</th>
<th>Frequency of Category in Group Decision Assignment (out of 27)*</th>
<th>Frequency of Category in Essay Decision Assignment (out of 318)**</th>
<th>Total Frequency of Category (out of 400)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific reasons</td>
<td>18 (32.73%)</td>
<td>9 (33.33%)</td>
<td>121 (38.05%)</td>
<td>148 (37.00%)</td>
</tr>
<tr>
<td>Cost</td>
<td>1 (1.82%)</td>
<td>2 (7.41%)</td>
<td>45 (14.15%)</td>
<td>48 (12.00%)</td>
</tr>
<tr>
<td>Food v fuel</td>
<td>6 (10.91%)</td>
<td>5 (18.52%)</td>
<td>21 (6.60%)</td>
<td>32 (8.00%)</td>
</tr>
<tr>
<td>People affected</td>
<td>0 (0.00%)</td>
<td>0 (0.00%)</td>
<td>24 (7.55%)</td>
<td>24 (6.00%)</td>
</tr>
<tr>
<td>Vague/not much of a reason present</td>
<td>5 (9.09%)</td>
<td>1 (3.70%)</td>
<td>16 (5.03%)</td>
<td>22 (5.50%)</td>
</tr>
<tr>
<td>Speed/grow fast</td>
<td>13 (23.64%)</td>
<td>0 (0.00%)</td>
<td>7 (2.20%)</td>
<td>20 (5.00%)</td>
</tr>
<tr>
<td>Category</td>
<td>Score</td>
<td>Percentage</td>
<td>Score</td>
<td>Percentage</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-------</td>
<td>-------------</td>
<td>-------</td>
<td>-------------</td>
</tr>
<tr>
<td>Criteria/scores</td>
<td>0</td>
<td>0.00%</td>
<td>7</td>
<td>25.93%</td>
</tr>
<tr>
<td>Articles/class content</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Convenience</td>
<td>3</td>
<td>4.45%</td>
<td>2</td>
<td>7.41%</td>
</tr>
<tr>
<td>It works/alternatives may not work</td>
<td>5</td>
<td>9.09%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Economy</td>
<td>0</td>
<td>0.00%</td>
<td>1</td>
<td>3.70%</td>
</tr>
<tr>
<td>Easy to implement</td>
<td>4</td>
<td>7.23%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Availability</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Large scale production</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Chosen despite drawbacks</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Income/Profit</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Jobs</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Space</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Time frame</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Car companies</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Domestic production</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Government</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Harvesting</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Other modes of transportation (cars not needed)</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Table 4:

*Most popular rationales across all assignments with examples.*

<table>
<thead>
<tr>
<th>Rationale Category</th>
<th>Quick Decision Assignment Quote</th>
<th>Group Decision Assignment Quote</th>
<th>Essay Decision Assignment Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific reasons</td>
<td>“Considering all the info, if I had to choose one, Algae seems to be the most renewable, and carbon friendly.”</td>
<td>“Algae as a biofuel is the best decision because it is the cleanest source, eco-friendly, won’t disrupt the food supply, cheap, and will release less CO2 into the atmosphere.”</td>
<td>“Many of these solutions include preventing greenhouse gases, such as carbon dioxide, from being emitted into the atmosphere and finding other raw materials that could be used to produce ethanol rather than corn.”</td>
</tr>
</tbody>
</table>

*Note: Some groups had more than one rationale*

**Note: Some people had more than one rationale**
"I think algae has the most potential because it grows 60x faster growing than oil on land based on the last video shown."

"As we conversed about the different articles, we concluded that the use of switchgrass or algae would be most efficient, since it grows fast, gives off less emissions, and does not interfere with the food supply."

"Sugarcane - it was the best option based on our criteria."

"After much deliberation and filling out the table, we arrived at the conclusion that algae would be the best option based on our criteria."
Cost

“I think that algae has a lot of potential even though it is second generation because it can help the high food cost issue.”

“Garbage; does not compete w/ food, lowers emissions from fossil fuels, prices are lower, using waste to create fuels, and production of ethanol exclusively used for health purposes.”

“We made this decision all agreeing with this is the most cost efficient option.”

Discussion

This paper explores markers of FBL (scientifically-valid decisions and scientifically-informed rationales) as they change across a decision-making intervention. FBL is defined as the ability to make sound, scientifically-informed decisions regarding a botanical SSI. The process of developing FBL as a conceptual framework helps to narrow down the confusing definitions of scientific literacy, and to better elaborate on why this type of scientific literacy is useful (Parsley et al., In review; Laugksch, 2000; Liu et al., 2010). Previous work has characterized and explored functional scientific literacy and socioscientific issues, and my work builds upon this by incorporating the new aspects of
botanical literacy and botanical SSIs into my conceptual framework (Zeidler & Keefer, 2003; Zeidler & Nichols, 2009).

My study builds on previous literature in this area by observing changes in students’ decisions as they gain personal experience in decision-making regarding SSIs in the classroom, which helps to foster their interest and engagement in learning (Sadler, 2004; Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013). However, unlike previous work, I was interested in observing the changes in these decisions and the rationales behind them over time, particularly as they relate to FBL.

Across all three assignments at the UofM, the top choice students made to replace fossil fuels was algae. In this particular aspect, decisions did not change much over the course of the biofuels unit. However, this finding still indicates that although decisions did not change much, they do indicate that students may have demonstrated at least one marker of FBL in all assignments. Corn ethanol followed algae as second most common decision in the quick and essay decisions. However, in the group decisions, the second most popular decision was biofuels in general. Both algae and corn ethanol were discussed at length during the course (algae was covered in the textbook used for the class, and the benefits and drawbacks of corn ethanol were covered via articles distributed in class).

Students may have made these choices because they were familiar with these options the most from class (and, in the case of corn ethanol, from their use of corn ethanol mixed with fossil fuels at the gas pump). It is interesting that the second most popular decision changed from corn ethanol to general biofuels in the second (group
decision-making) assignment. This may point to group decision-making being treated differently amongst students, as they are forced to discuss and defend their ideas to one another. Students completed the quick and essay activities alone, which may be a factor in the second most popular decision being corn ethanol in both of these assignments.

Regardless, all three of these decisions are considered scientifically valid as they do not contribute to the continued use of fossil fuels and emissions of greenhouse gas. The fact that the most common decision aligned with FBL across all three assignments is noteworthy, as the first assignment (quick decision) took place on the first day of the biofuels unit. At this point, students had been given little instruction on biofuels and as such, it would be feasible for students to make a decision that was not scientifically informed. This calls into question whether students were using science or familiarity to drive their decisions, especially during the first (quick decision) assignment.

Additionally, across all three assignments students cited scientific rationales the most often. The proportion of rationales that were scientifically-informed even slightly increased over the unit. This could be because student FBL was increasing, although it is difficult to say this for sure without further investigation. It may also be that students were making decisions based off of which options were familiar to them, and then using scientific information gleaned from the course to support these decisions.

One example of this is the quick decision activity and its second most common rationale category: speed of growth. Students viewed a video about algae and how fast it is to process into biofuel. This is also evidenced by cost being the second most common rationale category in essays, as students received articles (as well as the algae video) that
informed them of some of the costs inherent in these two choices of biofuel. This idea is further supported by the trend that referencing the assignment itself was the second most common rationale in the group assignment. Based on all of this evidence combined, it appears that students are indeed influenced by the information and assignments they receive in class.

The changes in second most common rationale categories over time indicate a slight increase in this particular marker of FBL (due to the increase in scientific rationales) which is not reflected by the decision data. This could reflect that as students progress through the unit, they learn more from the class and use this information more often in their decision-making as well. This type of short-term chronological study has not been explored within the context of SSIs and decision-making to my knowledge, as many studies in this area are focus upon building student empathy, reasoning skills, and differentiating between formal versus informal thinking (Dauer, Lute, & Straka, 2017; Sabel et al., 2017; Sadler, 2004). Thus, this study contributes to the literature by tracking student decisions and rationales over time.

This paper also contributes to the literature by providing a new real world example of how plants are relevant to students’ lives. Rather than using medicinal plants and recreational drugs, I utilized SSIs with the intent to allow students to see that plants have a real-world implication within their lives (Pany, 2014). Given that students did utilize scientific information from class more as they progressed through the unit, this approach could possibly also help students build their botanical literacy, as one of the issues associated with botanical illiteracy is an inability to understand the impact of plants upon human affairs and the biosphere (Uno, 2009). My study supports this idea as
I observed several students making scientifically-valid decisions that would positively impact the environment and reduce the use of fossil fuels (and the emission of greenhouse gases) as a result.

While this study did incorporate elements of both fast and slow thinking, it was not my focus to coerce students to switch from one to the other as previous studies have focused upon (Alred & Dauer, 2020; Dauer et al., 2017; Kahneman, 2011; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019). Instead, I sought to understand how decision-making can change over the course of a biofuels unit focused on decision-making and across multiple assignments within that unit.

If instructors are looking to improve FBL in a short-term intervention, it may be very important to introduce extra information about the botanical SSI itself (in this case, biofuels) as early as possible into the intervention. In the case of this study, the early introduction of information (and a quick decision assignment) about biofuels seemed to get students to understand how much of a problem fossil fuels are, as indicated by the high proportion of students choosing algae. The introduction of the video about algae early on also appears to have had an effect on student rationales for choosing algae as a biofuel, as students cited speed of growth as their second most common rationale for this decision. It may also be helpful to use a textbook that incorporates botanical (and other types of) SSIs to help students see how these topics relate to their everyday lives.

In order to engage students differently with the material, it may also be of value to incorporate different styles of assignments within an intervention. Given the increase in scientifically-informed rationales and the slight variations in rationales that were second
most common, students may have different thoughts regarding the botanical SSI in different contexts. One example of this is when students chose biofuels in general as their second most common rationale in the group decision, while corn ethanol was second most common in the quick and essay decisions. Perhaps incorporating group work can allow students exposure to different perspectives regarding the botanical SSI.

In conclusion, this paper offers a new approach of observing markers of FBL and how they change over time within a botanical SSI-based unit. The value of FBL lies in that it can improve both functional scientific literacy, and botanical literacy. The former is appropriate for undergraduate-level education as it is an intermediate form of literacy between non-mastery and mastery, while the latter is frequently overlooked in biological education (Laugksch, 2000; Uno, 2009). It also allows for a more specific, measurable definition of botanical literacy in a new context when currently, botanical literacy is simply defined as what students should know about plants (Uno, 2009). FBL also aims to improve student decision-making regarding SSIs, a functional goal that is shared by many forms of science literacy (e.g. Alred & Dauer, 2020; Dauer et al., 2017; Roberts & Bybee, 2014; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019). These skills are not only important in the classroom, but are vital in being able to function as a member of a scientifically-literate populace.

Limitations

This study is limited by a lack of time in the UofM course to spend on instruction regarding fast and slow decision-making. Despite this, readers can still get a sense of how to assess FBL over time and what instruction can help address FBL in the classroom.
Future work should explore further demographic diversity and a greater diversity of course types.

**Acknowledgments**

We would like to acknowledge Dr. Jenny Dauer and Dr. Brandi Sigmon for allowing us to collect data regarding the structure of their course and within the course itself. We would also like to acknowledge the University of Memphis Center for Biodiversity Research for funding our trip to UNL to collect these data. Finally, we acknowledge Sarah Baker and Eman Yonis for their assistance in data analysis.
Appendices

Appendix A.

*UNL Module Assessment* (used with permission from Dr. Jenny Dauer)

Name: _______________________________ Group: ______________ Instructor: __________ LA: ________

**STUDENT WORK GOES HERE:**

1. Define the issue:

<table>
<thead>
<tr>
<th>OPTIONS</th>
<th>Type your 1st option here</th>
<th>Type your 2nd option here</th>
<th>Type your 3rd option here</th>
<th>Type your 4th option here</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRITERIA</td>
<td>Metric: Performance score:</td>
<td>Metric: Performance score:</td>
<td>Metric: Performance score:</td>
<td>Metric: Performance score:</td>
</tr>
<tr>
<td>Type your 1st criteria here</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight:</td>
<td>Multiply the weight x the performance score in this cell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type your 2nd criteria here</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Information, Step 4: justification of assigning your performance scores:

**Criteria 1:**

**Criteria 2:**

**Criteria 3:**

6. Choice:
A) Choose an “option” based on the analysis undertaken.

B) Why do you think this is the best option?

C) What are the tradeoffs (positive and negative aspects) associated with the option you chose?

7. Review (Reflect on your own decision-making process using these steps):

A) Who are the stakeholders who are “winners” and “losers” if this option is implemented?

B) Some of the options are not necessarily mutually exclusive, and more than one could potentially be implemented at the same time. Are there other options (either the ones listed or other things that you can think of) that you would like to see implemented to help solve this problem?

C) Do you think your chosen option is viable to be currently implemented in our society, and would work effectively to resolve the issue? Why or why not?

D) Did working through the slow-thinking decision-making framework (7 steps) result in your thinking differently about the issue? How?

8. Assigning Resources Let’s say you have $10 million dollars to allocate towards any of these options for solving the problem. How would you allocate the money? Place $ amounts on one or more option to indicate how you would spend this money (it can all go to one option or could be split among several options):
Status quo: gasoline and diesel are dominant (corn ethanol is primary biofuel, biofuels are supposed to increase in volume over the next 20 years)

Support second generation biofuels (corn stover, sorghum, switchgrass etc) (by increasing federal government spending on research and development or subsidies for these fuels)

Promote and subsidize electric cars and renewable energy (homes and business would produce their own solar or wind energy to power vehicles)

Municipal solid waste to fuel (research and development money to develop turning garbage into fuel)

Educate and motivate to drive less and fly less (Effective approaches and incentives need to be determined.)

9. Importance of issue - Is this issue an important issue?

Rank the issue on a scale of 1 (not at all important) to 10 (one of the most important issues): ___________ Why?
10. Impact - Is there anything you could do to impact this issue? What are some things you could do?

11. Your Actions - Do you think your actions regarding this issue will make a difference? Why or why not?
Appendix B.

Quick decision assignment at UofM

1. Should we use corn ethanol as a fuel source? To what extent? Explain your reasoning.

2. Should we replace corn ethanol with another biofuel? To what extent? Explain your reasoning.

3. What biofuel has the most potential (considering all the advantages and disadvantages of each)? Explain your reasoning.
Appendix C.

*Group decision assignment at UofM*

Real World Scenario II

Group Work

Stakeholders (who will be impacted by these decisions)

Criteria (what is important to consider – make sure you include considerations of all stakeholders above)

1.

2.

3.

4.
5.

Options (what are the possible solutions)

1.

2.

3.

4.

Complete the table and scoring to make your final decision.

Group decision (include why you made this decision)
Appendix D.

*Essay decision assignment at UofM*

Real World Scenario 2 Paper

*to be completed individually, not with your group

10 points

**Directions** (1 point)

5. Reflect on the Real World Scenario discussion and decision you made with your group and write a 1-2 page response that includes answers to each of the questions below. This paper will not be graded as correct or incorrect (it contains your own thoughts and opinions). However, in order to get full credit for this assignment, your responses must demonstrate that you have meaningfully considered the questions and answers and put forth effort to reflect on the topics. Papers less than 1 full page will not receive full credit. Headings do not count toward the 1 page minimum.

6. Type your responses with double-spaced text in 12-point Times New Roman font, and one inch margins.

7. **Be sure to include citations for any references you use.**

8. Turn the paper in to the dropbox on eCourseware before class on **November 19**

**Questions to answer** (3 points each)
4. Provide a summary of your group discussion and the decision your group reached. Describe your process of reaching the decision and differences in opinion you had. How did the papers you read influence your decision?

5. Describe your own decision and how you reached it. Was your decision different from your group’s? Why or why not? What additional factors did you consider in your decision?

6. Reflect on the decision-making process. Do you feel you were able to make an informed decision? What other resources or information would you need to make a decision like this in a real scenario outside of class?
References


CHAPTER 6: DISCUSSION

Overall Remarks

Plant awareness disparity (PAD, formerly plant blindness) is the idea that students do not notice plants in their environment as often as animals (Parsley, 2020; Wandersee & Schussler, 1999). Past work in the field of PAD has established a description of the problem itself and the four components that make up PAD, examined causes and reasons for why PAD exists, and introduced multiple interventions designed to help address PAD in education (Balas & Momsen, 2014; Hershey, 2002; Krosnick et al., 2018; Parsley, 2020; Schussler and Olzak, 2008; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman, 2006; Ward, Clarke, & Horton, 2014; Yorek, Sahin, & Aydin, 2009). It is important to note, however, that without a way to measure PAD, it is difficult to determine whether the interventions proposed actually address the entirety of the concept of PAD, rather than only one component of it.

Additionally, while the idea of piquing student interest in plants via herbal medicines or recreational plants has been proposed, very few ideas for how to address PAD incorporate the student interest components, let alone all four components of PAD (Pany, 2014; Pany et al., 2019). Furthermore, calls have been made to incorporate socioscientific issues (SSIs) into botanical education, calls which have largely gone unanswered until now (Amprazis & Papadopoulou, 2018; Krishnan et al., 2019).

Findings from this work begin to address both of these issues by developing new ways to potentially address PAD that builds on student interest in SSIs. These new tools and approaches allow for future instructors to approach PAD from a more holistic point of view, rather than focusing their efforts solely on student attention to plants.
Overall, the significance of this work largely lies in two separate attributes: further characterization of PAD and a potential new approach to addressing PAD. The development of the Plant Awareness Disparity Index (PAD-I) contributes a new way of characterizing PAD. This instrument provides a measure of the entirety of PAD and all of its components, as opposed to previous efforts which only focused on attention or attitude (Balas & Momsen, 2014; Fančovičová & Prokop, 2010). The significance of this instrument is that it will allow instructors to determine the extent to which their interventions to address PAD in their classroom are effective. Additionally, it was during the instrument study (Chapter 2) that I discovered that traditional general botany courses may improve attention and knowledge components of PAD, but on their own, they do not improve the relative interest and attitude components of PAD. This was reflected in the pilot study of the instrument and has informed the rest of this dissertation. Interest and attitudes play an important role in the second attribute of this dissertation’s significance: a potential new approach to addressing PAD.

This new approach to addressing PAD is known as Functional Botanical Literacy (FBL) and it places special emphasis on the interest and attitudes components. This approach avoids previous assumptions that increased knowledge of plants will decrease PAD automatically (e.g., Hershey, 2002; Krosnick et al., 2018; Uno, 1994; Ward, Clarke, & Horton, 2014). Additionally, FBL provides the means for improving student PAD levels and increasing their botanical and scientific literacy skills. Botanical and functional scientific literacy are two very important components of FBL as they target the issues associated with PAD from two separate angles: that of plants (necessary to address PAD) and that of SSIs and science literacy (necessary to appeal to student interest and improve
decision-making skills). This approach is significant not simply because it is novel (though the use of SSIs in combination with plants has never been done before, to my knowledge) but because it will provide students with the skills they need to be productive members of a scientifically literate populace. Furthermore, the use of this approach in three of the studies in this work (Chapters 3-5) establishes a small body of literature surrounding FBL to support instructors in using this novel approach.
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Population</th>
<th>Topic</th>
<th>Research Questions</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Undergraduate</td>
<td>Initial</td>
<td>1. To what extent does the PAD-I demonstrate face validity?</td>
<td>PAD-I</td>
</tr>
<tr>
<td></td>
<td>biology students</td>
<td>development and validation of the Plant Awareness Disparity Index</td>
<td>2. To what extent does the PAD-I demonstrate concept validity?</td>
<td>Interviews from pilot study (Chapter 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. To what extent does the PAD-I demonstrate structural validity?</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Undergraduate</td>
<td>Pollution without People: Evaluating Plant Awareness Disparity and</td>
<td>1. What aspects of PAD do students exhibit when they talk about plants?</td>
<td>PAD-I</td>
</tr>
<tr>
<td></td>
<td>botany students</td>
<td>biology majors and Disparity and</td>
<td>2. To what extent does a students’ level of PAD correlate with the factors they associated rubric scores</td>
<td></td>
</tr>
</tbody>
</table>
environmental science minors) Student Perceptions of the Role of Humans in Plant-related Socioscientific Issues
choose to include in causal maps of ecosystems? 3. In what ways do students consider the role of society, specifically of humans, within ecosystems?

4 Undergraduate Characterizing Functional Botanical Literacy: Exploring a Conceptual Framework for Addressing Plant
mixed majors in a science course, and nonmajors in
1. To what extent do students in a science literacy course for mixed majors demonstrate markers of functional botanical literacy? 2. To what extent do students in a general biology course for nonmajors demonstrate markers of functional botanical literacy? Student interviews from both courses

Module assessments from science literacy course  
Student essays from general biology course
a general biology course Awareness

3. What comparisons can be made between FBL levels in a science literacy course for mixed majors and FBL levels in a general biology course for nonmajors?

5

Undergraduate mixed majors in a science literacy course, and undergraduate nonmajors in a general biology course

Chapter 5: How Decision Making about a Botanical Socioscientific Issue Changes

1. How does decision-making change over the course of a decision-making intervention in a general biology course?

2. How do student rationales behind their decisions change over the course of a decision-making intervention in a general biology course?

Module assessments from science literacy course

Quick decision assignment from general biology course
Group decision assignments from general biology course

Student essays from general biology course
Chapter Summaries

Chapter 2

Approach

First, I designed and developed an instrument known as the Plant Awareness Disparity Index (PAD-I) (Chapter 2). The research questions for this study were as follows: “To what extent does the PAD-I demonstrate face validity?” “To what extent does the PAD-I demonstrate concept validity?” “To what extent does the PAD-I demonstrate structural validity?” While I used the Plant Attitudes Questionnaire as an example of what types of questions can be asked about attitudes toward plants, the rest of the items were based on the four components of PAD, as well as ideas gathered from the literature (Fančovičová & Prokop, 2010; Wandersee & Schussler, 1999). The original version of the PAD-I included 30 items, and the final version includes 25 Likert-style items. I collected data from undergraduate biology students via two major science education list serves and conducted exploratory factor analysis with direct oblimin rotation and maximum likelihood factor extraction to demonstrate structural validity. I repeated this process twice, and upon the second round of data analysis, I determined a stable factor structure was present in the instrument.

I also utilized interviews from a pilot study of the original PAD-I to demonstrate concept and face validity (Chapter 3). I coded the interviews to look for markers of higher or lower PAD via student experiences with, and opinions about, plants. For example, if a student scored high on the PAD-I, (which indicates low levels of PAD) I would expect them to have more experiences with plants that were positive than that of a
student with a lower score. I have shown that this instrument is valid and reliable in undergraduate biology students, and I have demonstrated that students qualitatively demonstrate their PAD levels which correspond well with their PAD-I scores.

Results and Implications

The six factors of the PAD-I directly correspond with the four components of PAD: Attention toward Plants (for the attention component), Necessity of Plants/Importance of Plants (for the knowledge component), Caring for or Investment in Plants, and Positive Affect toward Plants (both make up the attitude component), Plants Better than Animals, and Animals Better than Plants (both make up the relative interest component). This will allow investigation into whether previously suggested interventions for PAD truly address the entirety of the problem, rather than one component of PAD or an idea related to it (e.g., Hershey, 2002; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman 2006).

Previously, there were no self-report measures of PAD and no way to measure all four components of the phenomenon. The Plant Attitudes Questionnaire was developed to measure attitudes toward plants in Slovakian students, ages 10-15 years old (Fančovičová & Prokop, 2010). However, this questionnaire does not measure PAD as a whole (only student attitudes) and is only validated in a specific demographic background. Other studies focused on using proxies such as student attentional blink, ability to name plants and animals, and textbook images to determine if PAD was present (Balas & Momsen, 2014; Brownlee et al., accepted; Link-Perez et al., 2010; Schussler & Olzak, 2008). It is noteworthy that the attitude and relative interest components each have
two sub-categories as factors in the instrument. This is likely due to the complex nature of student attitudes and interests in plants, something that has previously never been quantitatively captured.

Furthermore, findings from this study highlight the fact that while traditional botanical education can improve the knowledge and attention components of PAD, it does not address the relative interest or attitude components. This critical result will pave the way for future efforts to design and evaluate interventions that truly address the entirety of PAD, rather than one or two components. It also supports the literature indicating that engaging student interest should be an important part of botanical education (Pany, 2014; Pany et al., 2019). Finally, this finding informed the rest of the dissertation, as each successive study targets student interests and attitudes specifically to avoid previous assumptions that improving student knowledge of plants will also improve their PAD. In addition to characterizing PAD more fully, this study informed the development of a novel approach to mitigate it as well.

**Limitations**

Limitations of this study include potential overlap in subjects due to the use of the same listservs to collect data twice during factor analysis. The PAD-I is a self-report measure and is limited by participants’ potentially biased opinions of their behavior. The survey validation was only conducted with US-based undergraduates in biology-related courses. Therefore, the instrument will need validation again if intended for use outside of the US, in a different language, or in another course context.
Chapter 3

Approach

Second, I developed and explored a new conceptual framework known as functional botanical literacy (FBL). FBL is defined as the ability to make sound, scientifically-informed decisions regarding botanical SSIs such as genetically modified organisms (GMOs), plant conservation, climate change, and biofuels. I explored the PAD and SSI aspects of this framework by using causal maps to determine if students automatically link plants with SSIs when given an image prompt that demonstrates both (e.g. the image includes a field of growing crops as well as a factory releasing carbon emissions into the air, signifying climate change).

The research questions for this study were: “What aspects of PAD do students exhibit when they talk about plants?” “To what extent does a students’ level of PAD correlate with the factors they choose to include in causal maps of ecosystems?” “In what ways do students consider the role of society, specifically of humans, within ecosystems?” I collected student PAD-I scores (utilizing the first version of the PAD-I), pre and post causal maps, and student interviews.

I explored the interviews for markers of the four components of PAD to determine what aspects of PAD were present when students spoke about their experiences with plants. To determine how students consider the role of society, specifically of humans, within ecosystems I evaluated these causal maps based on the number and types of connections made within them and scored them using a structured rubric based on how well students connected various components of their map. I then investigated whether
any of the rubric scores from the causal maps correlated with PAD-I scores, to determine what types of relationships should be highlighted and asked about in student interviews. I finally used the interviews to explore student ideas about plants in relation to humans, to determine if students talk about human and plant related SSIs in interviews about their experiences with plants.

**Results and Implications**

Previous work has called for more efforts to link plants and various types of botanical SSIs together. Examples include PAD leading to a lack of knowledge about the illegal wildlife trade and how it affects plant conservation, calls for more food and agriculture content to be taught to bring attention to PAD and problems for our food systems, and calls for better coverage of plants in primary school curricula to highlight their importance to human welfare and biodiversity (Amprazis & Papadopoulou, 2018; Krishnan et al., 2019; Margulies et al., 2019). As this study was exploratory, I did not target a particular type of botanical SSI.

Instead, I first explored the PAD and SSI components of this framework and determined that students do not automatically consider plants in the context of SSIs, even with the help of a tool such as causal maps. Targeted instruction—both on how to use the causal maps themselves and on how to apply plants to SSIs and real-world situations—is required for FBL to even be possible in students. Even though the human links scores from causal map rubrics were the only ones that correlated with PAD-I scores, students still did not improve their ability to connect plants and humans to SSIs in the causal maps. While students do center their experiences with humans (especially plant mentors)
in their thinking about plants, they need instruction on how to integrate the role of humans into ecological and botanical issues on a larger scale (such as that of SSIs). This is true despite the fact that students’ PAD-I scores were correlated with their human links scores on the causal maps themselves. Students simply do not automatically connect plants, people, and the planet in the context of SSIs.

Chapter 3 demonstrates how FBL was established and how to determine if students in a class demonstrate the raw skills necessary to begin developing FBL. In the future, this can also be explored in other contexts using the same tools to determine if other students can connect plants and SSIs on their own. This is an important direction moving forward, as one of the limitations of this study is that it was done in a small botany course for biology majors and environmental science minors rather than in a larger course with a higher diversity of students. Additionally, this particular study population was not very diverse as the college itself is a small one in the Midwest and has little demographic diversity. Using these tools to explore FBL in other contexts is an important way that this framework can continue to contribute to approaches to mitigating PAD.

**Limitations**

Limitations of this study include small sample size, low demographic diversity within the botany course and overall college, and less time within the trimester to complete the study and administer the causal maps (than what would be possible within a typical semester). In order to circumvent these limitations, these methods can be applied to more diverse classes with greater demographic diversity. However, these results do
apply to general botany courses which is valuable due to their ability to help circumvent
PAD.

Chapter 4

Approach

Third, I considered all aspects of FBL together and characterized what FBL looks
like in two different contexts: that of a science literacy course and that of a traditional
general biology course for non-majors. The research question for this study were: “To
what extent do students in a science literacy course for mixed majors demonstrate
hallmarks of functional botanical literacy?” “To what extent do students in a general
biology course for nonmajors demonstrate hallmarks of functional botanical literacy?”
“What comparisons can be made between FBL levels in a science literacy course for
mixed majors and FBL levels in a general biology course for nonmajors?” I used
decision-making assignment data within each course and interviews that I conducted
across both courses. I evaluated these data sources using a classical content analysis
coding scheme that breaks down each component of FBL and important questions to
consider when evaluating student data for FBL levels (Saldana, 2013). This scheme
evaluates student decisions for their scientific validity, student rationales for their
inclusion of scientific information, and the scientific information within those rationales
for misconceptions. I then conducted frequency counts of each component of FBL to
determine whether the science literacy course or general biology course had higher
overall FBL levels. I repeated this process for all three data sources.
Results and Implications

Previous work in this field only explored certain aspects of FBL (Parsley et al., in review; Parsley et al., in progress). Much of the work regarding decision-making and science literacy focuses on how students make their decisions, rather than what those decisions are and what factors affect those decisions (Alred & Dauer, 2020; Dauer et al., 2017; Kahneman, 2011; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019). Furthermore, this particular study is unique in that it establishes FBL as a goal for instructors to incorporate into their courses. It also establishes what to look for and how to determine whether students have FBL skills, where previous studies have mainly explored parts of FBL and whether or not students engage in them, as well as what variables affect that engagement (Chapter 4; Parsley et al., in review; Chapter 5; Parsley et al., in progress).

It is worth noting that students improved their FBL skills greatly even after one intervention in a course that was otherwise largely focused on content knowledge. The finding that even one intervention can make a difference in student FBL skills is significant, as many instructors are required to teach a certain amount of traditional content in their biology courses and therefore often cannot devote their entire course to decision-making skills. Even so, just one intervention can still make major improvements to these skills in undergraduate biology students. Additionally, it is interesting that two different data sources used in the same way to get at how much FBL each course demonstrated showed slightly different results that seemingly contradicted the other data source. The interview data demonstrated slightly different trends in how much scientific information was used to make decisions in each course, and this may be because student
interviews have no effect on their grades. It would appear that course context and grading strategy are both consistent variables that affect FBL and should be considered carefully moving forward, along with other variables such as demographic background, socioeconomic status, and cultural beliefs. An important use of this study is to help educators know what to look for when evaluating students’ levels of FBL so they can look for the same hallmarks in their own students when attempting to improve their FBL and the related skills associated with it.

Chapter 4 demonstrated what FBL looks like in two very different contexts: a science literacy course for mixed majors and a general biology course for nonmajors. The choice of these two contexts essentially marks two ends of a spectrum. The finding that students in a science literacy class were better at FBL than those in the general biology for nonmajors course makes sense in the light of the nature of their instruction: the science literacy course included lots of scaffolding and feedback for students to develop decision-making skills more thoroughly. The use of these very different courses will allow future studies and instructors to demonstrate what these skills look like in other contexts (such as a general biology class for majors). Additionally, the evaluative tool I used to code the data in chapter 4 will also be useful for future studies and instructors as it can be used in any course context and sets an example for what components should be sought out in future data to determine FBL levels.

**Limitations**

There was limited time in the general biology course to cover decision-making as a skill, which may have affected students’ ability to use these skills as compared to the
science literacy course. Additionally, the less-structured nature of the general biology assignment made direct comparisons between each course difficult. Lastly, the specific demographic background of each course makes generalizing these results to other demographic backgrounds unrealistic. Extra time for the decision-making component to be taught, testing the intervention in more classrooms, and targeting more demographically diverse courses can help circumvent these problems. Despite the limitations, this study is still valuable in that it tests differences in diverse interventions in a systematic way.

Chapter 5

Approach

Last, I explored how student decision-making changes over time within a decision-making intervention. The research questions for this study were: “How does decision-making change over the course of a decision-making intervention in a general biology course?”, and, “How do student rationales behind their decisions change over the course of a decision-making intervention in a general biology course?” To explore these questions, I examined three different assignments within the general biology course: a quick decision, a group decision, and an essay decision activity used at the beginning, middle, and end of the biofuels unit, respectively.

To examine how student decision making changes over time within a decision-making intervention, I used descriptive coding and categorical content analysis to determine what types of decisions were present in each of the three assignments within the general biology course (Saldana, 2013). I then generated frequency counts for each
category to compare decisions across the assignments. I repeated this process with the rations behind the decisions in the course and used descriptive coding of the rations followed by categorical content analysis to generate categories of the rations. I also conducted frequency counts to see how often each category occurred within each assignment. This approach stems directly from the definition of FBL: the ability to make sound scientifically-informed decisions regarding botanical SSIs. I used scientifically-informed decisions and the rationales behind them to help me determine whether students were using science to make sound decisions, which act as markers for the overall goal of FBL stated above.

**Results and Implications**

Previous work in this field has focused upon getting students to switch from fast to slow thinking in their decision-making process (Alred & Dauer, 2020; Dauer et al., 2017; Kahneman, 2011; Sabel et al., 2017; Sutter et al., 2018; Sutter et al., 2019). However, rather than focusing on how the students made their decision, I explored how student decision-making changes over time. FBL is the first approach to utilize decision-making and SSIs with the intention of eventually addressing PAD, and therefore, students may make decisions differently based on different reasons because of the new use of botanical SSIs. As such, I decided it was better to focus on exploring how student decision-making changed over the course of the three assignments, so future studies can move forward with exploring the relationship between FBL and PAD. This approach allows for more contextual knowledge of how FBL can change in these interventions, which helps establish a small base of literature that future instructors and researchers can use later on.
I determined that an intervention targeted to develop FBL skills in students can make a difference in students’ levels of FBL even in a class that is not already designed to teach decision-making skills. I used scientifically-informed decisions and rationales as markers of FBL within each assignment and discovered that across all three assignments, the most popular decisions and rationales were scientifically-informed (indicating that students were possible developing FBL). Additionally, the proportion of scientifically-informed rationales actually increased slightly across the three assignments, which potentially points to a trend in which students ability to use science to support their decisions was improving (a skill that is central to developing FBL, as the ultimate goal of FBL is to make sound, scientifically-informed decisions regarding botanical SSIs).

These findings contribute further characterization to FBL and continue the trend of using scientifically-informed decisions and rationales as markers for observing and exploring FBL in students. Additionally, this paper contributes more information on how these markers can change over the course of a decision-making intervention where previous studies have not taken this temporal approach, and instead opted for singular comparisons using assignments from two different courses and interviews (Chapter 4; Parsley et al., in progress). This will help instructors to better understand how they can observe FBL in their course, as well as structure their own assignments and interventions in a way that will hopefully improve students’ FBL levels even further than what was seen in my study.
Limitations

The specific demographic background of the course makes generalizing these results to other demographic backgrounds and course contexts unrealistic. More studies in a wider variety of demographic backgrounds and courses are warranted. Despite limitations, this study demonstrates how FBL markers can change during a decision-making intervention, which is valuable to instructors who intend to use such interventions in their own courses.

Conclusions

Previous work regarding PAD has largely examined causes for and interventions to improve this phenomenon in students at many levels (e.g. Balas & Momsen, 2014; Hershey, 2002; Lindemann-Matthies, 2005; Schussler & Olzak, 2008; Strgar, 2007; Wandersee, 1986; Wandersee, Clary, & Guzman, 2006). However, previous efforts in these areas have largely focused on attempting to improve student attention to plants, and they often assume that if students learn more about plants, that attention will improve on its own (Uno, 1994; Hershey, 2002; Strgar, 2007). However, I have demonstrated that this is not true via the survey data collected in chapter 2 that showed a change in only the attention and knowledge components of PAD after an active learning botanical curriculum. Because of this, I have posited that targeted assessments and interventions need to incorporate all four components of PAD. To target these needs, this dissertation was guided by the following questions:

1. In what ways can PAD be better characterized?
2. How can PAD be addressed from a holistic point of view, rather than focusing solely on student attention to plants?

3. What tools or approaches can address PAD from this new, holistic perspective?

4. What effect does time have on the efficacy of these tools?

In what ways can PAD be better characterized?

The PAD-I characterizes all four components of PAD through a quantitative self-report measure. It is the first survey of its kind and has the benefit of focusing on all four components of PAD, not just attention such as previous picture-based assessments have (Balas & Momsen, 2014; Schussler & Olzak, 2008). Additionally, the development of FBL as a conceptual framework is a holistic perspective designed to address PAD. Exploring and testing this framework has allowed for a better overall characterization of FBL, which in the future will allow for more studies exploring how FBL and PAD actually relate to one another.

The answer to this question is significant because in the past, studies have focused largely on the attentional and knowledge components of PAD. This dissertation (and the answer to this question in particular) is expanding upon the previous body of work by providing evidence that it is important to consider all aspects of PAD both in assessments and interventions. Essentially, this dissertation is attempting to dispense with the idea of a knowledge deficit model of PAD, wherein student knowledge is the main roadblock to improved PAD levels. The knowledge deficit model is a term that originated in science communication research and it refers to the idea that if scientists just share more scientific knowledge with the public, the public will appreciate science more. This model
is outdated and has largely been disproven within the science communication community, but still seems prominent within PAD research (Besley & Tanner, 2011; Frisch et al., 2010; Krosnick et al., 2018; Ward, Clarke, and Horton, 2014; Wyner & Doherty, 2019). The findings that the attitude and relative interest components of PAD did not change after an active learning botanical curriculum are the first piece of evidence presented that indicates this knowledge-deficit model is not working, because if it were, all four components of PAD would have improved after such a curriculum. Additionally, The development of FBL which was designed to address PAD more holistically is a suggestion for how future studies can potentially move away from this knowledge-deficit model and instead target student interest in botanical SSIs.

**How can PAD be addressed from a holistic point of view, rather than focusing solely on student attention to plants?**

The PAD-I is a more holistic instrument than previous assessments have been, and this will allow for the design and evaluation of more holistic interventions to address PAD. Results from chapter 2 indicate that traditional botany teaching may improve attention and knowledge but will not (on its own) improve interest and attitudes toward plants. This lays the groundwork for future efforts to ensure that all four components of PAD are considered when developing new interventions. Additionally, FBL itself is a holistic approach designed to address PAD while having the added benefit of improving students’ scientific and botanical literacy (Chapter 3). This work builds on the previous suggestion that student interest should be an important part of botanical education by incorporating botanical SSIs to potentially capture student interest and improve student decision-making skills.
As demonstrated in chapter 2, student PAD as a whole will not improve unless all four components are addressed in an intervention, and as such, all four components should also be present in the assessment to measure PAD improvement. Developing ways to look at PAD holistically is critical to being able to truly improve PAD, rather than just part of it or an idea relating to it. In future studies, using FBL to do this will hopefully allow for the improvement of PAD as a whole while also contributing science literacy skills that students can take with them beyond graduation.

What tools or approaches can address PAD from this new, holistic perspective?

Each and every study (Chapters 2-5) within this dissertation provides a new tool or approach (or, in one case, a new use for a pre-existing tool) for instructors and researchers alike to use in their efforts to reduce PAD. In chapter 2, the PAD-I survey is established and validated as a tool to measure PAD and all of its components. In chapter 3, causal maps were used as a tool to explore whether students naturally connect plants and SSIs on their own. In chapter 4, FBL was established and characterized, along with an approach to observing certain markers indicative of FBL. Observing these markers can help instructors determine whether or not their students demonstrate FBL. And finally, in chapter 5, I used a new approach of observing those same markers of FBL to determine how FBL changes during a decision-making intervention. It is noteworthy that scientifically-informed decisions were the most popular choice in each assignment, and that the percentage of scientifically-informed rationales increased slightly across all three assignments. This indicates that students’ FBL appeared to be improving over the course of the biofuels unit.
These tools and approaches are significant in that they allow for a starting point for instructors who wish to begin to address PAD and FBL in their classrooms. In essence, this dissertation provides not just a case for a new approach to PAD, but the building blocks to use that new approach in a variety of contexts (e.g., botany courses for majors, science literacy courses for mixed majors, and general biology courses for nonmajors). These tools and approaches can be used in further contexts beyond what is presented in this dissertation as well. These results give instructors the capability to use FBL in their classroom immediately, if they so choose. Otherwise, instructors and researchers alike would have to do a great deal of experimentation to determine how they can use FBL in their classrooms.

**What effect does time have on the efficacy of these tools?**

In chapter 5, I determined that there was a change in students’ decisions across the biofuels unit, indicating that student markers of FBL did change within the intervention. Additionally, the slight increase in percentages of scientifically-informed rationales indicates that students may have been improving in their ability to use science to inform these decisions. While the decision categories changed over time (from algae to corn ethanol and in one case, to general biofuels) the top decision categories across all three assignments were scientifically informed. However, because algae and corn ethanol were covered in detail within the intervention (in the textbook, a class video, and articles presented during class) it may be that students are choosing these decisions based on familiarity, but are then providing scientific evidence behind them.
Understanding how FBL markers change over time allows for more context for future instructors to explore these markers themselves by demonstrating how some changes in these markers sometimes occur. While these results are not necessarily generalizable to any type of course (as chapter 5 took place in a general biology course for non-majors) it does provide some examples of trends instructors may see in their own courses when using these types of interventions. Additionally, because I have chosen to establish FBL and what instructors can look for as indicators of FBL, later work can build upon mine by examining the relationship between FBL and PAD as well as the factors that help students switch from fast to slow thinking in the context of FBL (goals that were beyond the scope of this dissertation).

**Future Directions**

Future directions include exploring the relationship between FBL and PAD, determining how students can switch from fast to slow thinking in the context of FBL, and observing how other variables such as demographic background, socioeconomic status, and cultural influences influence FBL and PAD. For example, it is largely recognized by the botanical community that indigenous cultures value plants highly and are less likely to exhibit PAD to the same extent as western cultures. This phenomenon can be seen in the book, “Braiding Sweetgrass,” by Robin Wall Kimmerer. Additionally, more information is needed to determine exactly why students chose algae and corn ethanol most often and whether the reasoning behind these choices was scientific or driven by familiarity. Lastly, observing these FBL markers in different courses can tell us more about how these types of decision-making interventions can affect students’ decisions about botanical SSIs in new contexts. Targeted interventions can be even more
effective when paired with the appropriate assessment technique. Further efforts in these areas will help improve the problem of PAD and developing functionally botanically literate students that will appreciate how important plants are, both to the biosphere and to human affairs.

Concluding Remarks

Overall, my work provides new perspectives on PAD and new tools and approaches to potentially approach it more holistically. The PAD-I is the first instrument of its kind to measure PAD and all four of its components using a self-report Likert-style scale. This will allow educators to determine what levels of PAD their students demonstrate in biology courses at the university level. The PAD-I will also help researchers to determine if their interventions to address PAD are effective or not. FBL is also the first conceptual framework of its kind that is designed to target student interest in botanical SSIs as well as vital science literacy components (such as decision-making, SSIs, and botanical literacy) to eventually address PAD from multiple perspectives and help students understand the relevance of plants to their everyday lives. In the future, addressing PAD and FBL in education will also contribute to a more scientifically literate populace.
References


*Brownlee and Parsley share first authorship


Hershey, D. R. (2002). Plant blindness: "I have met the enemy and he is us". *Plant Science Bulletin*, 48(3), 78-84.


