USE OF SCAFFOLDS TO SUPPORT UNDERGRADUATE STUDENTS IN LEARNING AND UNDERSTANDING BIOLOGICAL CONCEPTS

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The biological sciences field is becoming increasingly interdisciplinary as it focuses on creating innovative new ideas and applications to address broad societal challenges (AAAS, 2011; NRC, 2009). Many undergraduate students take at least one biology course and, regardless of their career path, will encounter this increasingly interdisciplinary field. They will need a foundation of scientific understanding in order to make informed decisions about the science they encounter in their careers or in their everyday lives (NRC, 2012a). To accomplish this, undergraduate students need support to learn how to integrate individual concepts into complex biological systems in order to reach robust understanding. Providing feedback to students can help with this process, but it is often difficult for instructors to provide frequent and individualized feedback to students. However, instructors can support students to engage in self-regulation to monitor their own work, generate their own feedback, and use that feedback to improve their learning and understanding (Nicol & Macfarlane-Dick, 2006; Sadler, 1989; Wood, 2009). One way in which instructors can help students in learning to engage in these processes is through the use of scaffolds that support students until they are able to perform a task or behavior on their own. The focus of the work presented here is on two different types of scaffolds used in two different learning environments to support

students as they learned to engage in the metacognitive and self-reflective components of self-regulated learning. In the first study, undergraduate introductory biology students used post-assignment scoring rubrics with added reflection questions and instruction to learn to engage in metacognition and to consider their understanding of biological concepts. In the second study, undergraduate preservice teachers used formative assessment learning tasks to reflect on and enhance their own biological content knowledge, their evaluation of elementary students' biological content knowledge, and their understanding of formative assessment practices. Overall findings indicated that the scaffolds examined in each study supported undergraduate students in enhancing their biological content understanding and in learning to engage in the metacognition and reflection components of self-regulated learning.

DEDICATION

To Brian,

who knows all about the best-laid schemes and how very much it's about time.

To Mom and Dad,

who have always supported, always encouraged, and always believed.

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TABLE OF CONTENTS

CHAPTER 1: Introduction 1

CHAPTER 2: Introductory Biology Students' Use of Rubrics and Reflection Questions as Scaffolds to Engage in Metacognition and Enhance Understanding 26

CHAPTER 3: Scaffolding Preservice Teachers' Consideration of Life Science Concepts and Elementary Students' Ideas within Structured Formative Assessment Learning Tasks 76

CHAPTER 4: Synopsis and Conclusions 109

REFERENCES....................135

APPENDIX A: Study 1 Example of Assignment Rubric....................155

APPENDIX B: Study 1 Rubric Addition 160

APPENDIX C: Study 1 Surveys 161

APPENDIX D: Study 1 Post-Assignment Interview Protocol 164

APPENDIX E: Study 1 Post-Exam Interview Protocol 166

APPENDIX F: Study 2 Course Survey Questions....................168

APPENDIX G: Study 2 Assignment 1 - Seed Dispersal....................171

APPENDIX H: Study 2 Assignment 2 - Skeletal System 173

APPENDIX I: Study 2 Assignment 3 - Habitats....................175

APPENDIX J: Study 2 Formative Assessment Assignment Prompts....................177

APPENDIX K: Study 2 Interview Protocol....................178

APPENDIX L: Study 2 Formative Assessment Assignment Rubric 179

APPENDIX M: Project IRB Approval....................184

LIST OF MULTIMEDIA OBJECTS

Figure 1.1: Conceptual Framework …………………………………………………..15

Table 1.1: Overview of Studies 25

Table 2.1: Interview Groups with Rubrics Received 37

Table 2.2: Data Collection Summary 40

Table 2.3: Metacognition Code Descriptions and Examples..42

Table 2.4: Descriptive Statistics for Selected Likert-Style Survey 1 Statements about Rubrics 45

Table 2.5: Interview Summary: Students Using Rubrics and Reflection Questions.........47

Table 2.6: Descriptive Statistics for Selected Likert-Style Survey 3 Reflection Question Statements 53

Table 2.7: Percent of Students Engagin in Rubric Uses: Interviewed vs. Non-interviewed Students..59

Table 2.8: Percent of Students Agreeing with Selected Survey Statements.....................60

Table 2.9: Percent of Interviewed Students Engaging in Rubric Use 60

Table 2.10: Score Differences between Interviewed and Non-interviewed Students.......61

Table 2.11: Score Differences between Reflection Question Users and Non-Users 63

Table 3.1: Correlations with Self-reported Comfort with Biology 91

Table 3.2: Regression Analysis of Pretest Performance Predicting Assignment Performance 92

Table 3.3: Descriptive Statistics of Assignment Scores 92

Table 3.4: Number of Interview Reflections on Formative Assessment Practices 101

Table 4.1: Study Summaries 117

CHAPTER 1

INTRODUCTION

The field of biological sciences is in the process of undergoing a major transformation from what was in the past more distinctly defined disciplines, to interdisciplinary fields that integrate ideas and applications to create innovative new discoveries (AAAS, 2011). Biological research is now focusing on large, complex data sets and modeling in order to address "complex and increasingly interdisciplinary problems" (AAAS, 2011, p. 3). The "New Biology" is "an integrated and interdisciplinary approach to biology" that is emerging to address broad societal challenges in food, environment, energy, and health (NRC, 2009, p. 3). Many undergraduate students take at least one biology course, regardless of whether or not they enter biological careers. Although not all students will choose careers in science, all will encounter science in their everyday lives and need a foundation of scientific understanding in order to make informed decisions (NRC, 2012a). Undergraduate life science education must adjust to match the changes in the scientific field to effectively prepare students to make decisions about biology-related issues in their lives, prepare future biological scientists to be successful in the field, and prepare future teachers to have the biology content knowledge they need to teach. This involves supporting students to think about integrated, dynamic systems that involve concepts at multiple levels of organization and to learn core ideas, practices, and crosscutting concepts that define the field (AAAS, 2011; NGSS Lead States, 2013; NRC, 2012a).

Providing this type of support for biological learning involves a focus on students' ideas as the foundation of science learning environments. Students have preexisting ideas

that may not be complete or scientifically accurate (Donovan & Bransford, 2005). Learning involves making sense of new experiences and ideas and either fitting them into the preexisting framework, or modifying the framework to create a new, revised way of thinking about particular scientific concepts (Donovan & Bransford, 2005). Both instructors and students play important roles in this sense-making process including the development and progression of scientifically-accurate ideas.

One approach that may help achieve this goal is to more specifically support undergraduate students in connecting their preexisting ideas about biological concepts to the development of more complex understanding. Feedback from instructors can help students see where they need to focus their learning efforts, but students can also engage in self-regulated learning and generate their own reflective feedback to this same end understanding (Nicol & Macfarlane-Dick, 2006; Sadler, 1989; Wood, 2009). Students can become aware of their own learning processes and develop skills to assess their own learning, though they may need to learn how to do this most effectively (Sadler, 1989). Specifically, students' engagement in metacognition and reflection can help them see how well they understand an idea and identify what they need to know to understand it better (Sinatra & Taasoobshirazi, 2011; Zimmerman, 2000).

This type of assessment of students' own ideas can be enhanced with support from a variety of scaffolds. Scaffolds are structures that support students to engage in a task or behavior until they can do so on their own (Pea, 2004). Rubrics with embedded instructions and questions for reflection are one type of scaffold that can help students develop metacognitive skills and connect biological concepts across topics. Though rubrics are often used as evaluation tools, they can also be used as teaching tools to help

students consider and improve their work (Andrade, 2005). Past research has examined how undergraduate students use rubrics generally (e.g., Andrade & Du, 2005; Panadero & Jonsson, 2013; Reynolds-Keefer, 2010), but more understanding is needed to determine how students could use rubrics to engage in metacognition, generate and use their own feedback, and enhance their understanding of biological concepts.

Undergraduate students who are preservice teachers could also use scaffolds to reflect on and learn to formatively assess elementary students' ideas or reflect on their experiences with learning how to teach life science concepts. Formative assessment is not widely used in elementary classrooms, potentially due to the fact that elementary teachers do not fully understand how to engage in the practice or have the appropriate amount of content knowledge to be able to effectively evaluate students' ideas (Coffey, Hammer, Levin, & Grant, 2011; Otero & Nathan, 2008). This is supported by past research that has shown preservice teachers with more content knowledge are able to more effectively engage in formative assessment practices (Sabel, Forbes, & Zangori, 2015). Therefore, innovate ways are needed to support preservice teachers in both learning biological content knowledge as well as learning to engage in effective instructional practices—such as formative assessment—that will allow them to teach those biological concepts to their students (Ball, Thames, & Phelps, 2008; Forbes, Sabel, & Zangori, 2015a; Haefner & Zembal-Saul, 2004; Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2013). One possible solution is structured formative assessment learning tasks used as scaffolds to support preservice teachers as they learn to engage in these practices.

In these ways, undergraduate students may be able to reason about how concepts that are new to them fit within biological concepts they already understand so they can

form a more integrated, complex understanding. Further, preservice teachers can have the added benefit of developing necessary skills to engage with their own students' ideas about biological concepts. More work is needed to determine the types of scaffolds and the conditions of their use that will most effectively support students in engaging in self-regulated learning, specifically metacognition and reflection, so that they can enhance their understanding of biological concepts and of the practices they will need to use to engage in the field. To that end, the work presented here focuses on undergraduate students' use of rubrics and reflection questions within an introductory biology course, and on preservice teachers' use of structured formative assessment learning tasks within an integrated biology content and teaching methods course. This work examines the extent to which these scaffolds affect undergraduate students' engagement in self-regulated learning and their understanding of biological concepts.

Study Rationale

Biology learning experiences for undergraduate students emphasize many complex biological processes. However, these processes are often taught as loosely connected facts rather than as dynamic systems (Hmelo-Silver & Azevedo, 2006; Wilson et al. 2006). To effectively think about and understand these dynamic systems, students should learn to analyze information and find patterns and relationships rather than memorize discrete facts (Hmelo-Silver & Azevedo, 2006; Wilson et al., 2006). While students need to understand the parts of the system, they must also see how those parts fit into the whole. To achieve this, instruction should focus more on conceptual—rather than procedural—aspects of the content (Duncan & Reiser, 2007). Students need multiple exposures to the integral parts and relationships that make up dynamic systems to

develop robust conceptual understanding (Smith & Knight, 2012). This allows students to make connections among concepts throughout the semester, and together, these factors can lead to longer-term retention (Dauer & Long, 2015; Smith & Knight, 2012).

Some conditions that may promote this learning include encouraging students to actively seek new information, organizing information for students in a meaningful way, giving students the opportunity to explain the ideas to other students, and prompting students to engage in metacognition to examine their own learning progress (Huba & Freed, 2000; Tanner & Allen, 2005). Although alternative conceptions about biological topics have been documented in multiple studies, they may not actually be misconceptions, but rather an indication of confusion about the topic compounded by a difficulty with combining independent ideas into a larger, integrated whole (Lewis & Wood-Robinson, 2000; Marbach-Ad & Stavy, 2000; Smith & Knight, 2012). To understand these complex topics, students must be able to create explanations about mechanisms and to arrange different levels of components into proper relationships and hierarchies (Duncan & Reiser, 2007). Preservice teachers will also need additional support to learn how to translate those biological concepts into their own classrooms, and will need to understand both the concepts and effective means to teach those concepts to their students (e.g., Ball et al., 2008; Forbes et al., 2015a; Haefner & Zembal-Saul, 2004; Nowicki et al., 2013).

Feedback can lead to improved learning if it gives students specific information about what they did well and what they need to improve upon in their work (Black & Wiliam, 1998). Unfortunately, it is difficult for instructors to provide feedback that is frequent and directed enough to be helpful to individual students; this is particularly true

for large, undergraduate science classes (Wood, 2009). Innovative strategies must be implemented to provide the kind of feedback that can be directed toward individual students, even in large-enrollment classes. Students can take a proactive role in understanding their own learning by monitoring their own work and generating and using feedback to adjust their strategies (Nicol & Macfarlane-Dick, 2006; Sadler, 1989), but more work is still needed on how to enhance this self-regulation (Nicol & Macfarlane-Dick, 2006).

Various supports can be included within courses and programs to serve as scaffolds to help students progress to greater understanding. Some past work has examined how scaffolds can be used in science learning environments with varying success (e.g., Barab et al., 2009; Novak, 2003; Puntambekar & Kolodner, 2005; van Es & Sherin, 2002; Zembal-Saul, Munford, Crawford, Friedrichsen, & Land, 2002). However, very little research has focused on the use of scaffolds to support self-regulated learning in science learning environments (e.g., Azevedo & Hadwin, 2005; Choi, Land, & Turgeon, 2005). Therefore, more work is needed to determine the types of scaffolds that will, first, engage students in the types of biological thinking that will be required of them within the demands of the current and future biological field, and second, help students engage in self-regulated learning and close the gap between what they know and what they have the potential to learn, particularly in the absence of individualized feedback from instructors.

The approach here is to examine how scaffolds can help students engage in self-regulated learning—particularly in metacognition and reflection—to consider how well they understand topics in order to then take steps to achieve deeper understanding.

Students who engage in metacognition have both better performance and greater learning gains (e.g., Anderson & Nashon, 2006; Baird, 1986). Further, prompting students to engage in metacognition can help them change their alternative conceptions to more scientifically-accurate conceptions (Tanner & Allen, 2005). This work is needed because it has potential to provide new opportunities for student learning gains and to help students develop ways of thinking that will allow them make sense of, and reason with, complex biological concepts. In particular, this work will help to address the gap in current knowledge as to the design and implementation of scaffolds that will best support students in engaging in self-regulated learning and in enhancing their understanding of complex biological concepts. As such, it has important implications for the design of scaffolds and courses that integrate scaffolds to effectively support students' in learning and understanding biological concepts.

Theoretical Framework

This work is grounded in contemporary learning theory and dimensions of scaffolding, self-regulated learning, and metacognition. These rely on connecting instructional support to students' ideas to help them develop robust, scientifically-accurate understanding.

Contemporary Constructivist Learning Theory

Students come to science classrooms with a variety of pre-existing ideas that are based on their own experiences and may be sensible to them, but may not be complete or scientifically accurate (Donovan & Bransford, 2005). These initial ideas can be used as a foundation to build more complex, scientific understanding (Greeno, Collins, & Resnick, 1996). Instructors must engage these initial understandings in the classroom for students

to incorporate new ideas they learn into their existing framework. In addition, students need to recognize their own ideas and then build on them or modify them to make sense of the world (Sadler, 1989). If this does not occur, students will fail to understand new concepts and only achieve surface learning, rather than deep learning (Harlen & James, 1997).

Knowledge of the world is constructed from our perceptions and experiences and how those are mediated by previous knowledge (Simon, 1995). Learning takes place when a new experience does not fit into prior understanding and new or modified conceptions are created to make sense of the new information (Simon, 1995). If the everyday understanding of natural phenomenon that students have is markedly different from the scientific representation, students may have difficulty in learning the scientific concept (Driver, Asoko, Leach, Mortimer, & Scott 1994). Individuals incorporate new knowledge when they can see how it fits into their own experiential world, but may abandon that knowledge if the idea does not fit within their experience (Roth & Roychoudhury, 1994). Constructions are tentative models that students use, test against their experiences, and modify, as needed (Driver & Oldham, 1986). As a result, students need to have access to problems that allow them to use their prior knowledge and to engage in scientific practices (NGSS Lead States, 2013).

Sense-making and knowledge construction involve both social and cognitive dimensions (Cobb, 1989; Simon, 1995) and so involve both personal and social processes (Driver et al., 1994). These processes occur in domain-specific manners. In order to understand science and scientific ways of knowing, students must engage in the ideas and practices of the scientific community, but must also make them meaningful at the

individual level (Leach & Scott, 2003). Engagement in these ideas and practices should include classroom interaction on shared problems in which individuals can interact with others in discussion and activity that will allow them to be a part of the community of discourse that involves particular concepts and conventions (Driver et al., 1994). However, students will also need time to engage in their own personal construction of ideas and sense-making (Leach & Scott, 2003). Students can construct knowledge based on their previous knowledge in many ways. Listening to direct instruction may be one of these ways as long as the student is considering prior knowledge and actively constructing new knowledge. Importantly, though, this still requires teachers engaging with students' ideas and guiding their interpretations in order to be effective (Otero & Nathan, 2008).

Conceptual change research has shown that students' awareness of conflict between their existing ideas about the natural world and those that exist in the science classroom can lead to changes in how students account for these experiences (Anderson, 2007). Some changes in conceptual understanding occur because of everyday experiences that students have while others require intentional intervention (Greeno et al., 1996). Students can more easily learn new concepts if they "fit within an existing conceptual structure" (NRC, 2007, p. 107). Major changes in how students think about concepts are more difficult to make because of their existing integration and organization of knowledge within particular frameworks and contexts. Students may need to make additions to, remove, or change aspects of their existing conceptual structure in order to incorporate new evidence (Clement, 2008; Kober, 2015). Both experience and

instructional interventions can support students to construct new understanding of concepts and strengthen their understanding of new ideas (Otero & Nathan, 2008).

Zone of proximal development. The *zone of proximal development* (ZPD) describes the space between what students know and what they can learn with guidance and assistance from others (Vygotsky, 1978). A person with more experience can support and create structure for someone with less experience to learn to navigate ideas and perform processes (Driver et al., 1994). Learners' upper learning boundaries are constantly changing as they incorporate more understanding and become increasingly independently competent (Brown et al., 1993).The ZPD draws attention to the roles that other individuals (such as teachers, parents, and peers) can play in extending a students' attempts to understand (Puntambekar & Hubscher, 2005). Although learning must have some self-directed elements, students are able to learn more with support than they are alone (Carey, 2004; Puntambekar & Hubscher, 2005; Vygotsky, 1978; Wood, Bruner, & Ross, 1976). With science learning in particular, intervention with someone who is more knowledgeable is essential for students to begin to understand concepts within the particular discourse of the scientific culture (Driver et al., 1994).

In some situations, such as with formative assessment, a teacher and student may engage in a way that both are learning from each other's ideas in a co-constructed ZPD (Ash & Levitt, 2003). Teachers collect information about learners' understanding and compare that against the expectations they have of what the learner understood and still needs to understand. A teacher's ZPD is engaged by a student in understanding the students' ideas, and the teacher can then use that information to create responsive

instruction that will engage the student's ZPD toward a more advanced scientific understanding (Ash & Levitt, 2003).

Scaffolds as Cultural Tools

A *scaffold* is a structure that supports learners until they can perform a task or produce a behavior on their own, and *scaffolding* is a process whereby different aspects of a particular activity are structured in such a way as to help leaners until they can act independently (Pea, 2004). Scaffolding was initially conceived as an interaction between a tutor and a student so that the tutor provided support to help the student with ongoing learning (Puntambekar & Hubscher, 2005; Wood et al., 1976). This type of scaffold helps a student to accomplish a task or solve a problem with support and can then be removed when the student no longer needs it (Puntambekar & Hubscher, 2005; Wood et al., 1976). In this way, scaffolds help learners bridge the ZPD by providing guidance and assistance to support them in moving beyond what they currently know to reach more advanced understanding.

Over time, this definition of scaffolding has expanded to include various types of tools that support student learning (Puntambekar & Hubscher, 2005). These tools can be seen as "cultural artifacts" because they combine mental functions with tools that have been shaped by human practice and are accessible only externally, rather than internally (Cole & Wertsch, 1996, p. 250; Pea, 2004). These cultural artifacts mediate student activity and transform "mental functioning in fundamental ways" by introducing new functions, making some mental processes unnecessary, and reorganizing behaviors (Cole & Wertsch, 1996, p. 252; Vygotsky, 1981). The idea of these various tools used as scaffolds and as cultural artifacts aligns with the idea of the ZPD in that students are

supported by more capable tutors through the use of these artifacts that help extend their current understanding (Cole & Wertsch, 1996).

Self-regulated Learning and Metacognition

Self-regulated learning (SRL) consists of "the active control by students of some aspects of their own learning" (Nicol & Milligan, 2006). Both internal and external feedback are important components of SRL, but an increased capacity to assess oneself and generate internal feedback is fundamental to developing SRL (Boud, 2000; Nicol & Macfarlane-Dick, 2006; Yorke & Knight, 2003). Students can take a proactive role in understanding their own learning by monitoring their own work and generating and using feedback to adjust their strategies (Nicol & Macfarlane-Dick, 2006; Sadler, 1989). For these approaches to be effective, students must have support to reach an understanding of what good work is and how to develop their work to meet the higher standard (Sadler, 1989). Past research has shown that students can learn how to self-regulate their learning and that those who regulate their own learning have greater success in school (Pintrich, 2000; Zimmerman & Schunk, 2001). However, the idea that students can be a primary source of their own feedback is a relatively new idea (Andrade, 2010) and more extensive examination on how to enhance self-regulation within science education is needed (Nicol & Macfarlane-Dick, 2006).

Sinatra and Taasoobshirazi (2011) have considered self-regulated learning as having three major components: cognition, metacognition, and motivation. The cognition component consists of conceptual knowledge and problem-solving skills that students need to be successful in performing scientific tasks. The metacognition component consists of the "knowledge and control of conceptual knowledge and problem-solving

skills needed for scientific proficiency," and the motivation component consists of what students require to "maintain the engagement and deliberate practice needed for scientific proficiency" (Sinatra & Taasoobshirazi, 2011, p. 205).

In addition, Zimmerman (2000) has suggested that self-regulated learning is composed of three phases that function in a cyclical manner. These three phases are (1) forethought, (2) performance or volitional control, and (3) self-reflection. Forethought takes place before students have begun an effort to learn and includes students considering their goals and expectations and engaging in strategic planning. Performance includes self-monitoring and managing learning strategies while students are learning. Finally, self-reflection takes place once learning efforts have ceased and involves students self-evaluating and reflecting on their task performance. Following self-reflection, students cycle back to the first step of forethought and begin the process again (Andrade, 2010). The framework for the studies here incorporates the three phases of self-regulated learning (Zimmerman, 2000) while focusing on metacognition as one of the major components (Sinatra & Taasoobshirazi, 2011).

Metacognition involves the awareness of one's own learning process (Wood, 2009) and includes both metacognitive knowledge and metacognitive regulation (Stanton, Neider, Gallegos, & Clark, 2015). Metacognitive knowledge is awareness of our own thinking, while metacognitive regulation is how we control that thinking in order to learn (Stanton et al., 2015). Asking students to be metacognitive and assign plausibility or intelligibility to their own ideas is one way to help students change their alternative conceptions to more scientifically-accurate conceptions (Tanner & Allen, 2005). The foundation for the metacognition aspect of this study is the three dimensions and related

questions as described by Grotzer and Mittlefehldt (2012). These include: (1) “Intelligibility: Does the explanation make sense to me?”, (2) “Plausibility: Do I think that the explanation is a possible explanation?”, and (3) “Wide-applicability: Can I apply the explanation beyond the contexts in which I have learned it?” (Grotzer & Mittlefehldt, 2012, p. 82). These three dimensions will serve as the primary foundation for examining undergraduate students’ ideas while they use instructional scaffolds to support them as they engage with biological concepts and move toward understanding.

Conceptual Framework

Combined, these ideas constitute a framework that integrates students’ idea development with principles of self-regulated learning and metacognition. Students begin with a preexisting idea and progress to a new or revised idea with support from both internal and external factors (Figure 1.1). External factors include aspects of learning environments to which both students and instructors contribute—such as attention to prior ideas, content instruction, student assessment, and responsive feedback. In the context of these factors, students can use the cycle of self-regulated learning to contribute to idea development. As a part of self-regulated learning, students can use metacognitive skills to consider the intelligibility, plausibility, and wide-applicability of the ideas. Scaffolds can help students and instructors bridge the external and internal factors and support learning. Ideally, the end product of these inputs and student thought processes is a new or revised idea.