

**Paula P. Lemons, Ph.D.**  
Assistant Professor of Biochemistry and Molecular Biology  
The University of Georgia

**Application for the University System of Georgia  
Regents' Scholarship of Teaching and Learning Award**

May 2014

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# The University of Georgia®

Office of the Senior Vice President for Academic Affairs and Provost

May 21, 2014

Regents' Teaching Excellence Awards Committee  
University System of Georgia  
270 Washington Street, SW  
Atlanta, GA 30334-1450

Dear Regents' Teaching Excellence Awards Committee,

It gives me great pleasure to provide this letter in support of Dr. Paula P. Lemons' candidacy for the FY2015 Regents' Scholarship of Teaching and Learning Award. As an Assistant Professor of Biochemistry and Molecular Biology, Dr. Lemons has distinguished herself as a teacher and researcher whose commitment to the instructional mission of the University of Georgia is unparalleled.

Dr. Lemons joined the faculty at the University of Georgia in 2009. Her work in the Biology classroom and in biology-based, scholarship of teaching and learning (SoTL) research has garnered her several national awards and led to numerous, grant-funded publications. From her ongoing work with the National Academies of Science Southeast Regional Summer Institutes to her article on assessing higher-order cognitive abilities being selected as *Science's* Editor's Choice winner to, most recently, receiving National Science Foundation funding for her collaboration on group assessment techniques for undergraduate biochemistry courses, Lemons' SoTL research has been path-breaking and highly recognized among her peers. Her extensive publications consider timely topics, such as empirical evidence in teaching decisions, web-based tutorials for students' development of problem solving skills, and student-centered instruction in the biological sciences.

Dr. Lemons' research is on the leading edge of scholarly teaching across the STEM disciplines incorporating student problem-solving techniques, particularly in large, introductory Biology classes and in building and testing SOLVEIT, an adaptive online tutorial that has the potential to transform how we think of hybrid instruction. As a recent Writing Fellow with the Center for Teaching and Learning, Dr. Lemons is known as a passionate and dedicated pedagogue. Her commitment to research-based teaching informs and shapes the learning experiences of her students, as well as the practices of her colleagues. Her profound impact on the teaching culture at UGA and her dedication to instructional excellence inspire my enthusiastic endorsement of Dr. Lemons' candidacy.

Thank you for considering her for the FY2015 Regents' Scholarship of Teaching and Learning Award.

Sincerely,

Pamela Whitten  
Senior Vice President for Academic Affairs and Provost



# The University of Georgia

**Stephen L. Hajduk**  
*Professor & Head*

*Department of Biochemistry and Molecular Biology*

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May 7, 2014

Regents' Teaching Excellence Award Committee  
University System of Georgia  
Board of Regents  
270 Washington St. SW  
Atlanta, GA 30334

Dear Selection Committee:

This letter is prepared in support of the nomination of Dr. Paula Lemons for the University System of Georgia-Regents' Scholarship of Teaching and Learning Award. Dr. Lemons joined the University in January of 2009 as a tenure track Biology Educator in the Division of Biological Sciences and the Department of Plant Biology. In August of 2012, Dr. Lemons accepted a tenure-track position as an Assistant Professor in the Department of Biochemistry and Molecular Biology at UGA. Recognizing her important contributions to the department in August of 2013, the BMB faculty voted to put Dr. Lemons forward for promotion to Associate Professor with tenure based on her exceptional teaching and research in biology education as applied to undergraduate instruction. Since joining the faculty of the University of Georgia Dr. Lemons has develop an innovative and well-funded research program and has introduced important changes to undergraduate instruction. She is recognized both at the University level and nationally as a leader in science education. Further, her leadership in instruction has been transformative within the department. I cannot imagine a more deserving candidate for the Regents' Scholarship of Teaching and Learning Award. She has my strongest recommendation

Beginning in the Spring of 2009 and continuing through the Fall of 2012 Dr. Lemon's primary instructional assignment has been two sections per semester of introductory biology, including BIOL 1104, Introductory Organismal biology, and BIOL 2108H, Honors Organismal Biology. BIOL 1104 is a course for non-science majors with nearly 300 students per section. In the past four years, Dr. Lemons has taught more that 2500 students in the course. BIOL 2108H is the second of two courses in the introductory biology sequence for science majors who are also honors students. Beginning in the Spring of 2013 her primary teaching assignment has shifted to BCMB 3100, Introductory Biochemistry, where she will teach three large (>900 students) per year. In addition, Dr. Lemons had taught a graduate level course PBIO 7360, Teaching Biological Science, a course in which graduate students gain classroom experience under direct supervision of a faculty member. In addition to classroom teaching Dr. Lemons has also mentored undergraduates, graduate students and postdoctoral fellows in biology education research. She has mentored five undergraduates in research, including two Research Scholars in the Peach State Louis Stokes Alliance for Minority Participation.

The excellence of her teaching is reflected in comments made in formal evaluations by students in her classes. Students in her class characterized her as an excellent teacher who challenged them and encouraged critical thinking yet genuinely cared about their learning. Despite teaching to large introductory classes of 150-300 students she worked to make the classes more engaging by learning students' names, forming large in-class discussion groups and utilizing case studies to teach basic concepts. Overall, Dr. Lemons is characterized by the students as a teacher who is student centered and pedagogically skilled. Dr. Lemon's teaching has also evaluated by faculty peer groups both in Plant Biology (2011) and Biochemistry and Molecular Biology (2013).



Uniformly the faculty found her teaching to be exemplary.

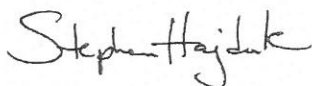
Dr. Lemons' important contributions to teaching have been recognized by others at the University and nationally. In 2012 and 2013, Dr. Lemons received the *UGA Innovative Instruction Faculty Grant*. In 2012, she used this funding to refine an online, problem-solving tutorial for BIOL 1104. In 2013, she used this funding to begin implementing flipped classroom sessions and case studies in BCMB 3100. Additionally, in 2010/2011, Dr. Lemons was selected as a *National Academy of Sciences Education Fellow in the Life Sciences*. This fellowship recognizes and promotes faculty from large research-intensive universities nationwide who are leaders in the field of biology education.

Since coming to UGA Dr. Lemons' research has addressed two basic questions: 1) What are undergraduate students thinking when they solve problems about biology? and 2) What factors influence biology instructors' teaching? Based on her success in publishing her finding in prestigious journals and obtaining grant funding she has made significant progress. Dr. Lemons' research, utilizes classroom-based assessments, interviews, and surveys analyzed through quantitative and qualitative methods, has uncovered several new and unexpected findings and has led to the publication of manuscripts in *CBE-Life Sciences Education*, including one manuscript that was recently selected as an Editor's Choice in *Science*. Since arriving at UGA Dr. Lemons has published four papers as either lead or corresponding author. In addition, she lists three manuscripts as submitted for publication at this time.

These research efforts were supported through extramural funding obtained through the *National Science Foundation (NSF): Course, Curriculum, and Laboratory Improvement program, Phase 2*. Since joining the faculty at UGA Dr. Lemons has received over \$560,000 in funding from federal and state agencies. In addition, she has recently received notification that a grant, that she serves as co-PI, which will be funded this year by NSF. This grant is for over \$500,000 and will run through 2018. She currently has three additional grants pending at NSF. Her national reputation in biology education research also has resulted in an invitation to author a chapter in the recently published book, *Using Reflection and Metacognition to Improve Student Learning* and invitations to present numerous talks and workshops around the country.

Based on her outstanding record in instruction and research and service, I strongly recommend that Dr. Paula Lemons for the University System of Georgia-Regents' Scholarship of Teaching and Learning Award.

Sincerely,



Stephen L. Hajduk, PhD  
Professor & Head





# The University of Georgia

Franklin College of Arts and Sciences  
*Division of Biological Sciences*  
**Dr. Peggy Brickman, Professor of Plant Biology**

May 1, 2014

Regent's Scholarship of Teaching and Learning Award Committee  
University System of Georgia

Dear Committee Members,

It is with great pleasure that I provide this letter of support for Paula Lemons' accomplishments as a scholar and researcher. I am a geneticist by training who now conducts research in education at the University of Georgia. I have taught introductory biology for the past 18 years first as an instructor, then lecturer, then rising through the ranks to full professor. Thus, I am only too familiar with the problems inherent to teaching and conducting scholarship at a large research university. I recruited Paula eight years ago to fill a new type of faculty position in a life-sciences department that had both a huge teaching expectation (over 500 students each semester) as well as the usual requirement of excellence in research. This new position had the additional challenge that the expectations for research did not involve scholarship in science (the field of the candidate's doctoral degree) but rather in the area of the scholarship of teaching and learning.

At the time of Paula Lemons' hiring, this type of tenure-track science education position was quite novel. We struggled to find someone with a biology Ph.D. who had both the teaching credentials needed to excel in our large-enrollment courses and the expertise to conduct education research. Paula has not only met all of the challenges of this type of position, but she is the proof that this model provides an excellent mechanism not only to improve the educational experiences of hundreds of undergraduates but also to provide inspiration and improvement in the teaching abilities of our fellow faculty. A rousing speaker, role model, careful theorist, and advocate for improving college teaching for all students, Paula epitomizes the qualities of the Regents Award for the Scholarship of Teaching and Learning.

Paula is one of the finest examples of an educational researcher who is able to effectively translate their pedagogical research so that it answers basic questions and simultaneously transforms the practice of teaching in the classroom. Paula routinely publishes her research in journals that are widely read by college science faculty rather than just those read by education researchers, and she tackles problems that are faced by every faculty member teaching college science courses. In most of her work, Paula has recognized a basic quandary – students rise to the challenges they encounter but most college-level science students are not regularly being challenged to master higher-order thinking skills in their courses. Determined to remedy this problem, Paula identified two major impediments. The first impediment was a lack of understanding by faculty about how to define these skills, and second was a difficulty in faculty's ability to assess these skills separately from content information. One of Paula's papers (in the widely-read journal *Bioscience* in 2006) described a method that could easily teach faculty to construct questions that could simultaneously and individually assess both content knowledge as well as higher-order critical thinking skills.

Paula has continued to publish influential papers characterizing the challenges faculty face implementing higher-order assessments. In each of her publications, her greatest contribution may be the frameworks she creates that help faculty overcome the difficulties she identifies, thus translating her research into practical measures that can be used for the improvement of instruction for all faculty. As a result of this work, Paula is sought as a nationally-recognized speaker in assessment at several faculty development projects including the National Summer Institutes in Biology Education sponsored by the National Academies of Sciences.

Paula has a continued interest in faculty improvement and development, an interest that has transformed the teaching culture in her research-focused Biochemistry department and also resulted in successful extramural funding from the National Science Foundation for several faculty development initiatives. Paula was co-investigator on a project that examined how teachers adopted Case Studies in the science classroom including work uncovering the factors that motivate faculty to adopt this teaching method as well as the type of professional development interventions that aid in successful implementation. She is currently the lead professional development investigator on a 5-year NSF WIDER proposal aimed at helping faculty use a new system to automate the process of grading open-response (short answer) questions. As part of this project, she has instigated a faculty learning community that will foster long-term collaborations among teaching faculty in our Genetics department here at UGA.

The best illustration of Paula's successes as a translator of pedagogical research into active practice, however, can be seen in how she has transformed the teaching in her own Biochemistry department. This department is famous on our campus as one of the most research-intensive. It is also infamous as having had some of the worst instruction in their core biochemistry course for biology majors. Largely based on her research acumen, but also on her skills as a communicator, Paula has effectively transformed the acceptance and respect for teaching among her fellow faculty colleagues. Since her hiring in this department, Paula has been chosen as lead course coordinator for the hundreds of students taking this course. She is observed by her fellow instructors, and for the first time these fellow instructors are seeking new teaching techniques and getting feedback on their courses from Paula.

Paula's ability to communicate instantly with diverse faculty in a calm and reflexive manner through both her publications and her personal speaking engagements have allowed her to transform the teaching and learning at the University of Georgia and across the country. She is a treasure for the state of Georgia, and I can't think of anyone more deserving of this award.



Marguerite (Peggy Brickman)

## Statement of Teaching Philosophy

Davi, Rajdeep, Michelle, Amanda, Lisa, and Jack laughed as they worked. I looked their way and listened. Yes, the laughter was on task; it was focused on the case study about dinitrophenol and its effect on oxidative phosphorylation. I wanted to know what was so funny, so I stopped and leaned into the circle, "What are you guys laughing about?" Rajdeep was the first to respond, "Well, Dr. Lemons, last week Jack, Davi, and I were studying oxidative phosphorylation. We had this idea to use a proton shuttle as a diet pill." Davi added, laughing, "Little did we know the drug had already been developed – and banned by the FDA!" The group burst into laughter and I did too. For about five minutes, the group and I talked about dinitrophenol and how it works to uncouple proton movement and ATP synthesis in the mitochondria. "I'm sorry your idea has already been attempted and failed," I joked with the group. But they quickly replied, "Oh, don't worry. We're thinking about a new, safer alternative, and we have some ideas!"

I know it sounds like a cliché, but a moment like this with students is enough to keep me getting out of bed for work for a year. Moreover, this example illustrates my goals for teaching and how I implement lessons to achieve my goals. I have four broad goals for students I teach. I want students to:

- Demonstrate understanding of biological concepts and principles.
- Develop skills in scientific problem solving.
- Describe multiple examples of the real-life relevance of biology.
- Be inspired to keep learning biology.

To help students achieve these goals, I use four guiding principles to help me decide how to structure my class:

- Focus on fundamental concepts, and deemphasize irrelevant details.
- Provide opportunities every class period for students to practice writing about biological concepts.
- Provide opportunities every class period for students to solve problems.
- Create learning objectives for every class period that I share with students. Align in-class activities and exams with the learning objectives.
- Create a classroom atmosphere that is friendly, supportive, challenging, and fun.

My courses have four characteristic features that illustrate these guiding principles. First, I use case studies. Case studies are a pedagogy that uses realistic or true narratives as the context for students to comprehend biological concepts and to solve problems. Every week in my course, students work in groups on a new case study, both in class in groups and individually outside of class. Second, I structure in-class time using questions. In advance of class, I predict the most challenging concepts and problems (e.g., from the case study). Then I write questions that allow me to assess student work on these concepts and problems. Because I commonly teach large courses, I ask questions via a student response system (i.e., TopHat). Based on students' responses to the questions, I modify instruction. For example, if most students write a correct answer to a question, I move on to the next question. But if many students respond incorrectly or incompletely to a question, I ask another question or ask



students to discuss the idea among their peers. I move on to the next question when, by talking to individual students or polling students, I detect widespread understanding or when I detect that students can quickly achieve understanding on their own outside of class. Third, my exams include questions that require students to explain concepts and solve problems we have worked on in class and to apply their knowledge and problem-solving skill to new problems. Fourth, I create a friendly, supportive, and fun course by being highly accessible and responsive to students and hosting a class party at my house. I also use Peer Mentors to facilitate student group work. Peer Mentors are previous students who earned excellent grades and demonstrate an interest in helping others learn. These support mechanisms show students that they have the resources they need to succeed, even though the work is challenging.

When students comment on my teaching, several themes emerge. Students recognize that I genuinely care about them as people and about their learning. Students like having the opportunity to learn how biology relates to real-life via case studies. Students do not have to cram for exams, because they study regularly in order to complete the cases. Students think that my exams are fair assessments of their learning. Students work very hard for my class; the hard work pays off, often with good grades, but even more often with a sense of deep learning and growth in problem solving. Students remember many things they learned in my class, even years after the course, for example, when taking another course or studying for the MCAT.

### **Rationale for My Teaching Strategies**

I teach the way that I teach because of the research literature on teaching and learning and also because of personal experience.

**Research Literature.** Teaching and learning theory and empirical investigations have provided a clear picture of best practices for the college biology classroom, for example: (a) Learners must build their own mental models and teachers can facilitate this by learning more about what their students know and can do (Novak 1977); (b) Personal response systems (i.e., TopHat) coupled with the use of peer discussion improves student performance on concept questions (Smith et al. 2009); (c) Cooperative learning pedagogies are more effective than traditional lectures in promoting retention and problem solving (Johnson and Johnson 1993). (d) Case studies can improve students' reasoning skills (Dinan 2002). (e) Students who practice solving problems guided by experienced peer facilitators show improved exam performance and retention (Tien et al. 2002). Similarly, Freeman and colleagues incorporated practice with problem solving and active learning into their introductory biology course and showed that the course performance of all students improved and that students from disadvantaged educational and socioeconomic backgrounds benefited more than others (Freeman et al. 2011; Haak et al. 2011).

**Personal experience.** As McAlpine and Weston demonstrate (2000), knowledge about teaching and learning can be gained when teachers reflect on students and student learning. I habitually reflect on my lessons, exams, and student work. I also reflect on interactions with students, end-of-course evaluations, and peer reviews of my teaching. Through reflection, I have turned experience into knowledge. The knowledge I have gained, in turn, has changed the way that I think about students, teachers, and all

aspects of a college course. Moreover, it has enabled me to solve problems in my teaching that have led to superior student outcomes.

For example, I used to save all of my most challenging questions for exams. I wanted to make sure that my exams were difficult and gave students novel opportunities to apply their understanding. But students regularly complained. For quite some time, I reflected on this feedback from students. I also read and conducted research that enlightened me. I recognized that by saving the hardest questions for the exams, I was missing the opportunity to coach students in how to solve challenging problems (van Gelder 2000; Freeman et al. 2011; Lemons and Lemons 2013). As a result, I made a conscious decision to change. I decided to use my hardest questions in class and to take plenty of class time to help students work through these problems. I also decided to alter my exams. Instead of asking mostly novel problems on exams, I began asking questions on exams that were directly related to the challenging question from class while also including questions based on novel scenarios. Students no longer complain about exams. Instead they report the in-class work is challenging, and it prepares them well to succeed on exams.

## **From Teaching to Research**

I integrate my teaching and research by attempting to understand how students like Davi, Rajdeep, Michelle, Amanda, Lisa, and Jack develop deep understanding of concepts like oxidative phosphorylation and the ability to apply those concepts to problems like the development of a safe diet pill or more pressing societal concerns.

## **Research Questions, Goals, Theories and Methods**

My teaching philosophy drives my research questions, which are: How do beginning and advanced biology students solve problems and how do their problem solving steps compare? To what extent do students' problem-solving steps predict their success in science and intentions to pursue a science career? Recently, I have pursued two research goals: I have: (1) Investigated biology students' problem-solving steps in evolution and ecology; and (2) Developed and tested *SOLVEIT* an adaptive, online problem-solving tutorial.

My research draws on literature from cognitive science, learning sciences, and education research. It assumes that a **problem** is a task that presents a challenge that cannot be solved automatically and that **problem solving** is a decision-making process where a person is presented with a task, and the path to solving the task is uncertain (Martinez 1998). Additionally, **success in science is operationalized as** earning relatively high grades in science courses, high GPA in a science major, and obtaining a college degree in science. **Persistence in science is operationalized as** intending to enroll in a science-related graduate program.

In the next two sections, I will discuss important literature that creates the theoretical basis for my research.

## **Practice in problem solving may help students succeed and persist in science**

To produce one million more STEM professionals in the next decade (White House 2012), more work needs to be done to understand why fewer than 40% of all

students and 16% of under-represented minorities who originally enroll in a STEM field in college receive a degree in four years (National Center for Education Statistics 2009).

The issue of student attrition is linked to “gateway” courses – large introductory classes that undergraduates take at the beginning of their undergraduate careers that are prerequisites for continuing in the major. In biology, reported failure rates in these courses range from 27-56% (e.g., Burrowes 2003). Not only do students fail these courses, they also leave science because of them (Tobias 1990; Seymour & Hewitt (1997; Seymour 2002).

Some evidence indicates that engaging students in problem solving improves their course performance. For example, Freeman and colleagues incorporated practice with problem solving and active learning into their introductory biology course and showed that the course performance of all students improved and that students from disadvantaged educational and socioeconomic backgrounds benefited more than others (Freeman et al. 2011; Haak et al. 2011). This line of inquiry suggests that course interventions can help students succeed in science courses (Sadler & Tai 2001).

Yet an important problem remains: What do effective course interventions do for students cognitively? Most intervention research focuses on the interventions themselves or on students’ grades (e.g., Smith et al. 2009). What we know little about is the actual cognitive activity of students as they work on the problems that teachers want them to solve. Only a handful of studies in biology explore the cognitive activities of students as they solve problems, and these studies are limited to evolution (e.g., Nehm & Ridgway 2011) and genetics (e.g., Smith 1992). **Thus, there is a need to study the cognitive aspects of student problem-solving in biology, investigate its relationship to success and persistence in science, and translate this research to more targeted course interventions.**

### **Theoretical Foundations for Problem-Solving Research**

Domain-specific problem solving has its origins in information processing theory (IPT) (Newell et al. 1958). IPT focuses on the cognitive processes used to reach a problem solution and emphasizes the general thinking processes people use when they attempt problem solving, such as working backward by beginning with the problem goal (Chi & Glaser 1985; Newell et al. 1958). Despite the empirical evidence for general thinking processes, one of IPT’s shortcomings as a comprehensive view of human cognition (Dawson 1998) is that the knowledge base of the problem solver is not considered.

Domain-specific problem solving expands IPT to recognize that experts in a particular domain have a more complete and well-organized knowledge base that enables them to solve the complex problems they face (e.g., Chase & Simon 1973b). Chi and colleagues were some of the first to show domain-specific problem-solving differences between experts and novices (Chi et al. 1981). Biologists have built on this work to confirm that, in general, experts classify problems based on deep features (e.g., the underlying concepts) while novices classify problems based on surface features (e.g., whether organisms are birds vs. bats) (Smith 1992; Nehm & Ridgway 2011).

Although the theoretical perspective of domain-specific problem solving has strengths, it has been criticized (Sternberg 1995). One criticism is the lack of attention to individual differences among groups of problem solvers (i.e., novices or experts).



Indeed, Nehm and Ridgway (2011) confirmed the importance of studying within group variation (Camacho & Good 1989) by showing that novices who solve problems about evolution vary significantly in problem classification patterns and problem solving abilities, even demonstrating expert-like approaches to problems (Nehm & Ridgway 2011). **These findings raise the question, what domain-knowledge elements and problem-solving skills account for such precocious practices among some undergraduates, and how can these factors be nurtured among other students?**

Recognizing the strengths and limitations of IPT and domain-specific problem solving, I have designed my research to:

1. Use the lens of IPT to identify general and characteristic problem-solving steps practiced by biology undergraduates.
2. Use the lens of domain-specific problem solving to investigate how biology undergraduates' organization of biology knowledge influences their problem solving. Specifically, I investigate the biological concepts of evolution, protein structure and function, and metabolism, because the Vision and Change report put forth these concepts as those that all biology undergraduates should understand (AAAS, 2011).
3. Focus on variations in problem solving among novices. I have identified variations in biology-specific problem solving among beginning biology students. In future research, I will also identify variation among advanced biology students, and between beginning and advanced biology students.

**In summary, my research explores how undergraduate students apply concepts during problem solving and addresses the critical need to improve student success and persistence in science by improving student learning in biology courses.**

### **Evidence of the Impact of My Research**

I have generated substantial evidence to demonstrate that (1) college biology students practice both supportive and unsupportive problem solving and (2) teachers can improve student problem solving by providing explicit instruction. My data lead to the hypothesis that supportive problem solving is a predictor of success and persistence in science. The potential impact of this research is that biology educators can build learning and teaching tools to increase the number of students who successfully prepare for biology career paths during their undergraduate careers.

### **College biology students practice supportive and unsupportive problem solving**

**Capturing and characterizing students problem-solving steps in a large-classroom setting.** As an instructor in Introductory Biology for nonmajors at UGA, I developed a protocol to capture students' written descriptions of their thought processes while solving problems on exams based on a think-aloud interview approach (Ericsson & Simon 1984). The steps of the protocol are: model the written think aloud in class, assign written think-aloud homework, review homework and give feedback, administer written think-aloud problems on exams, and use students' written think alouds as data. Using the written think aloud protocol, I collect student problem-solving data like that shown in Figure 1.

1. Read the question.
2. Know I'm looking for answer that includes viable fertile offspring. The fish have some similarities but not enough difference that I can't judge if they are the same species by sight. I also don't know about habitat or diet variances.
3. Looked over the chart.
4. The chart shows that hybrids can be produced but gives no information if they are viable and fertile.
5. Notice that just because number of hybrids increased from year 2 to 3 (10 to 14 hybrids) does not mean they can reproduce. It could mean that the benthics and limnetics produced more hybrids that year.
6. I don't have enough information to solve the problems so I choose answer E.

Figure 1. Written think aloud from an Introductory Biology student who had been taught how to do a written think-aloud about her problem-solving steps. The student was writing her thoughts about solving the problem shown in Figure 2.

My collaborator Luanna Prevost (University of South Florida) and I collected written think alouds from 154 Introductory Biology students solving thirteen different problems about evolution and ecology (e.g., Figure 2). We identified 27 problem-solving steps students used. A subset of these steps is presented in Table 1 to illustrate steps that are supportive or unsupportive of students' progress toward a correct and complete solution.

**Development of a strategy for creating valid problems.** We then used statistical methods to address the research question: What types of problems prompt students to use higher-order cognitive steps (Anderson & Krathwohl 2001)? We reorganized the problem-solving steps into higher-order cognitive steps (9 codes, e.g., Implementing) and lower-order cognitive steps (7 codes, e.g., Remembering). We determined the total number of higher- and lower-order steps used for each of the thirteen problems. Because the data were not normally distributed, we used the Wilcoxon ranked test to determine whether students used higher-order steps more frequently for any of the problems. Indeed, we identified five problems that prompted for significantly more use of higher-order steps compared to lower-order steps (Table 2). Four of the five problems required students to interpret visual representations they had not seen before in class or the textbook. For example, Figure 2 shows one of the problems, which focuses on evolution and incorporates new visual representations in the form of images and tables. Based on this finding, I hypothesize that problems with unfamiliar visual representations encourage the use of higher-order problem-solving steps. Moving forward in my research, I will study problem solving using problems that include visual representations that are new to students.

Sticklebacks are small fish found in a variety of habitats in the Northern Hemisphere. Two forms of sticklebacks have been identified – the Benthics and the Limnetics. Examine the pictures of the two stickleback forms and the data in Table A. What is the best conclusion you can draw from these data?



**Table A. Proportions of benthics, limnetics, and hybrids found in traps.** For three different years, traps were set for fish in Paxton Lake in British Columbia. The traps were regularly checked and the type of fish (benthic, limnetic, or benthic/limnetic hybrids) and the number of each type were determined. The relative proportion of each type for a single year is presented with the actual numbers counted in parentheses (McPhail 1992).

Year	Total	Benthics	Limnetics	Hybrids
1	1057	0.50 (528)	0.48 (509)	0.019 (20)
2	962	0.50 (479)	0.49 (473)	0.010 (10)
3	994	0.49 (491)	0.49 (489)	0.014 (14)

- A. Based on the morphological species concept Benthic and Limnetic fish are different species.
- B. Based on the phylogenetic species concept Benthic and Limnetic fish are the same species.
- C. Based on the biological species concept Benthic and Limnetic fish are the same species.
- D. Based on the biological species concept Benthic and Limnetic fish are different species.
- E. I need more information to draw a conclusion about whether Benthic and Limnetics are the same or different species.

Figure 2. Sample problem from the domain of evolution used to probe students' problem-solving steps.

Table 1. Student problem-solving steps organized based on whether the step is supportive or unsupportive of student progress toward a correct and complete solution. \* N=154 students

	Problem-Solving Step	Description
Supportive Steps	Global/Working forward	Identifies the scope of the problem early in the problem-solving process and, starting with the problem, defines how a solution can be achieved.
	Remembering	Remembers basic facts or concepts (i.e., declarative knowledge)
	Implementing	Carries out a task they have not practiced previously
	Negative checking	Explains why a choice is incorrect by comparing the choice to their knowledge or to the data provided in the question
Unsupportive Steps	Misunderstanding content	Shows evidence that they do not understand content
	Recognizing	Points out that a choice is correct or incorrect but does not say why
	Disregarding evidence	Overlooks evidence that is provided in the question, often stating that there is no evidence
	Contradicting self	Makes a statement (content or reasoning) early in the solution process that is contradicted later in the solution process

\*Written think-alouds were analyzed using a qualitative approach that is a hybrid between content analysis, which tests hypotheses (Bernard 2002), and grounded theory, which generates theory "grounded" in the data (Creswell 2007). The content analysis allows for testing and further development of theory related to IPT and novice-expert problem solving. For example, Global/Working Forward is a category derived from the concept of heuristics in IPT-based research. The grounded theory approach allows for discovery of new problem-solving steps (Charmaz 2006). For example, Remembering comes directly from student language; students frequently stated, "I remember." Students' problem-solving steps were analyzed in two phases: (1) All participants' problem solving steps were characterized and assigned to "codes." (2) Codes were grouped into themes relevant to research questions.

**Building and testing SOLVEIT an adaptive online problem-solving tutorial that teaches students to use supportive problem-solving steps.** Based on this work, we determined that some students were using problem-solving steps that helped them reach correct solutions regularly (i.e., supportive steps), but more students were using steps that interfered with reaching a correct solution (i.e., unsupportive steps). **We hypothesized that scaffolding students in supportive problem-solving steps could help unsuccessful problem solvers improve.** To address this hypothesis, we built a computer-based tutorial, *SOLVEIT*, grounded in the literature on scaffolding problem solving (e.g., Kim & Hannafin 2011). *SOLVEIT* includes two problems on evolution and one on ecosystems. All problems incorporate new visual representations in the forms of graphs and tables. *SOLVEIT* has linear navigation within six phases for each problem: (1) Define concepts; (2) Construct initial solution; (3) Assess problem-solving skills; (4) Check/Revise initial solution; (5) Reflect on/Describe problem-solving skills; and (6) Evaluate experts' solutions. Importantly, in Phase 3, the original problem is broken into several sub-problems presented in a multiple-choice format. If students have difficulty solving the sub-problems, *SOLVEIT* provides further help and aids such as immediate and explanatory feedback as well as interactive tutorials on analyzing data, drawing conclusions from data, etc.



My research group conducted an implementation study with introductory nonmajor students, using scoring rubrics to evaluate solution quality and semi-

Table 2. Five problems that elicited significantly more higher-order problem-solving steps (Wilcoxon test ;  $p > 0.05$ ). The content domain and problem features are shown. *New VR* = visual representation that was new to students. Types of visual representations included images, tables, graphs, schematics (Rybarczyk, 2011). Scientific data = Incorporation of data into the problem.

Content Domain	Evolution	Evolution	Content-Independent	Systems	Systems
Problem Features	New VR; Image; Table; Scientific Data	New VR; Graph; Scientific Data	New VR; Graph; Scientific Data	New VR; Schematic	Text Only
LO codes	53	134	71	38	58
HO codes	117	302	198	265	74

structured interviews and an online survey to examine student perceptions of the usability of *SOLVEIT*. Students' problem solutions improved from Phase 2 to 4, and students reported improved problem solving abilities. Students found the immediate feedback

and self-pacing helpful. We further tested *SOLVEIT* with introductory nonmajor students ( $N=149$ ) using a two-group, pre- and post-test, experimental design. Students were randomly assigned to a treatment ( $n=70$ ) or comparison group ( $n=79$ ). The treatment group used the full, scaffolded version of *SOLVEIT*. The comparison group used an alternative version that included the problems without scaffolds. Both groups completed *SOLVEIT* after Exam 1 but before Exam 2. We used analysis of variance (ANOVA) to compare mean scores from Exam 1 to 2 in the treatment versus comparison groups  $F(1, 149) = 4.061$ ,  $p = 0.046$ ,  $\eta^2 = 0.027$ . The treatment group score of 6.01 out of 7 was above the comparison group score of 5.44, with a small effect size of 0.027.

Additionally, preliminary analyses of student interviews from Fall 2012 show that students who have strong science literacy skills (Gormally et al. 2012) and high grades on Exam 1 display supportive approaches to problems, with minimal unsupportive steps. In contrast, students who have average to low science literacy skills and average to low grades on Exam 1 use many unsupportive problem-solving steps. Often average- and low-performing students are unable to solve the problems at all. **This has led us to hypothesize that supportive problem solving predicts success in science courses.**

## Future Research

My research on problem solving was recently recommended for funding by the NSF CAREER program. Moving forward, I will pursue the following research goals:

1. Investigate and compare beginning and advanced biology students' problem-solving steps in the domain of protein structure and function.
2. Investigate and compare beginning and advanced biology students' problem-solving steps in the domain of metabolism.
3. Determine the extent to which the use of particular problem-solving steps by biology students predicts their success and persistence in science.
4. Extend and test *SOLVEIT* an adaptive, online problem-solving tutorial for biology.
5. Launch a Biology Faculty Learning Community to support faculty teaching problem solving.

Through these future endeavors I will continue to generate scholarship that can improve student learning in the science classroom.

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### **EDUCATION**

**Ph.D.**, Biochemistry, University of Kentucky, 1999

**B.S.**, Biology, *summa cum laude*, Southern Wesleyan University, 1994

### **PROFESSIONAL APPOINTMENTS**

**Assistant Professor**, University of Georgia, Department of Biochemistry and Molecular Biology, 2012-present

**Adjunct Assistant Professor**, University of Georgia, Department of Math and Science Education, 2011-present

**Assistant Professor**, University of Georgia, Division of Biological Sciences and Plant Biology Department, 2009-2012.

**Assistant Professor of the Practice**, Duke University, Department of Biology, 2001-2008.

### **SELECTED HONORS AND AWARDS**

- Core Collaborator, NSF-Funded Core Collaborators Group for Assessment in Undergraduate Biochemistry, 2013.
- *Science* Editor's Choice for Lemons, P.P. and Lemons, J.D. Questions for Assessing Higher-Order Cognitive Skills: It's Not Just Bloom's. *CBE-Life Sciences Education*; March 22, 2013.
- Facilitator and Presenter, The National Academies of Science Southeast Regional Summer Institute on Undergraduate Education in Biology, 2012 – present.
- Writing Fellow, The University of Georgia, 2009-2010.
- Senior Fellow, Duke University Center for Teaching, Learning, and Writing, 2000-2003.

### **PUBLICATIONS**

[\*Indicates status as project leader and/or corresponding author.]

#### **Journal Articles on Education Research and Practice**

1. Andrews, T.M. and **Lemons, P.P.** (Submitted) "It's Personal: Biology Instructors Prioritize Personal Evidence Over Empirical Evidence in Teaching Decisions" *CBE-Life Sciences Education*.



- Kim, H., Prevost, L., and **Lemons, P.P.** (Submitted) "Students' Usability Evaluation of a Web-based Tutorial Program for College Biology Problem Solving." *Journal of Computer-Assisted Learning*.
- Herreid, C. F., Terry, D.R., **Lemons, P.P.**, Armstrong, N., Brickman, P. and Ribbens, E. (In press) "Emotion, Engagement and Case Studies" *Journal of College Science Teaching*.
- Lemons, P. P.** and Lemons, J. D. (2013) "Questions for Assessing Higher-Order Cognitive Skills: It's Not Just Bloom's." *CBE-Life Sciences Education* 12(1): 47-58.
- Andrews, T.M., Price, R. M., Mead, L. S., McElhinny, T. L, Thanukos, A., Perez, K. E., Herreid, C. F., Terry, D.R. and **Lemons, P. P.** (2012) "Biology Undergraduates' Misconceptions about Genetic Drift." *CBE-Life Sciences Education* 11(3): 248-259.
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#### Book Chapters and Features:

- Huber, S. K. and **Lemons, P. P.** (In press) "Threats to Biodiversity: A Case Study of Hawaiian Birds" in Herreid, C. F., Schiller, N. A., and Herreid, K. F. *Using Case Studies to Teach Quantitative Reasoning*. NSTA Press.
- Lemons, P. P.**, Reynolds, J. A., Curtin-Soydan, A, J. and Bissell, A. N. (2013) "Improving Critical-Thinking Skills in Introductory Biology Through Quality Practice and Metacognition" in Kaplan, M., Silver, N., LaVaque-Manty, D., and Meizlish, D. (Eds.), *Using Reflection and Metacognition to Improve Student Learning* (pp. 53-77). Sterling, VA: Stylus.
- Lemons, P.P.** (2001) "Teaching Postdocs: An Alternative Approach to an Academic Career," *Science Next Wave: Postdoc Network*, <http://nextwave.sciencemag.org/cgi/content/full/2001/10/04/7>.

#### Case Studies for Teaching Science:

- Lemons, P. P.** and Rothbaum, A. O. (Under review) "High or Hurt: Caffeinated Alcoholic Beverages' Effects on Intoxication," *National Center for Case Study Teaching in Science Case Collection*.
- Herreid, C.F. and **Lemons, P.P.** (2012) "Mendel Dreams: The Beginning of Genetics," *National Center for Case Study Teaching in Science Case Collection* [http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case\\_id=652&id=652](http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case_id=652&id=652)
- Prevost, L. and **Lemons, P. P.** (2011) "Mildred Using Plants: The Medicinal Value of Plants," *National Center for Case Study Teaching in Science Case Collection* [http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case\\_id=616&id=616](http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case_id=616&id=616).

#### Science Publications:

- Schraw, T. D., **Lemons, P. P.**, Dean, W. L., and Whiteheart, S. W. (2003) "A Role for Sec1/Munc18 Proteins in Platelet Exocytosis" *Biochemical Journal*, 374, 207-217.

2. **Lemons, P. P.**, Chen, D., and Whiteheart, S. W. (2000) "Molecular Mechanisms of Platelet Exocytosis: Requirements for a-Granule Release," *Biochemical and Biophysical Research Communications*, 267, 875-880.
3. Chen, D., **Lemons, P. P.**, Schraw, T., and Whiteheart, S. W. (2000) "Molecular Mechanisms of Platelet Exocytosis: Role of SNAP-23 and Syntaxin 2 and 4 in Platelet Lysosome Release," *Blood*, 96, 1782-1788.
4. Chen D., Bernstein, A. M., **Lemons, P. P.**, and Whiteheart, S. W. (2000) "Molecular Mechanisms of Platelet Exocytosis: Role of SNAP-23 and Syntaxin 2 in Dense Core Granule Release," *Blood*, 95, 921-929.
5. **Lemons, P. P.**, Chen, D., Bernstein, A. M., Bennett, M. K., and Whiteheart, S. W. (1997) "Regulated Secretion in Platelets: Identification of Elements of the Platelet Exocytosis Machinery," *Blood* 90, 1490-1500.

## **GRANTS FOR EDUCATION RESEARCH AND PRACTICE**

### **GRANTS - ACTIVE: [Total = \$728,312]**

- **Lemons, P.P.**, PI, Farmer, M, Co-PI, Moore, A.J. (2013-2016) National Science Foundation: Widening Implementation and Demonstration of Evidence-Based Reforms (WIDER) *Collaborative Research: A Community of Enhanced Assessment Facilitates Reformed Teaching*. \$225,557.
- Kaplan, J., PI, **Lemons, P.P.**, Co-PI (2013-2018) National Science Foundation: Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics Type 3 *Collaborative Research: Expanding a National Network for Automated Analysis of Constructed Response Assessments to Reveal Student Thinking in STEM*. \$502,755.

### **GRANTS – RECOMMENDED FOR FUNDING [Total requested = \$913,450]**

- **Lemons, P.P.**, PI. (2014-2018) National Science Foundation: Faculty Early Career Development (CAREER) Program. *CAREER: Problem Solving Skills as Predictors of Success and Persistence in Biology*

### **GRANTS – COMPLETED [Total = \$549,084]**

- **Lemons, P.P.** (2013). UGA Innovative Instruction Faculty Grants *Reinvigorating BCMB 3100 with Case Studies and Flipped Class Sessions* \$5,000.
- **Lemons, P.P.** (2012-2013). UGA Faculty Research Grants Program and UGA Innovative Instruction Faculty Grants *SOLVEIT An online, self-directed tutorial to teach problem-solving skills in biology* \$15,000.
- Herreid, C. F., PI, **Lemons, P. P.**, Co-PI, and Terry, D., Co-PI. (2009-2012). National Science Foundation: Course, Curriculum, and Laboratory Improvement Phase 2 (Expansion). *Case Study Teaching: How Do Questions and Emotional Engagement Impact Student Learning?* \$499,664.
- **Lemons, P.P.** (2011-2012). UGA Office of STEM Education *SOLVEIT Tutorials: How Do Online Problem-Solving Tutorials Using Faded Scaffolding Impact Student Learning?* \$9,000.

- **Lemons, P.P.** (2011-2012). UGA Faculty Research Grants Program *SOLVEIT Tutorials: Building and Testing A Set of Online Tools to Teach Problem-Solving Strategies in Introductory Biology*. \$9,975.
- **Lemons, P. P.** (2010-2011) UGA Office of STEM Education: *What Cognitive Steps Does Multiple Choice Testing Trigger?* \$6,000.
- **Lemons, P. P.** (2010-2011) UGA Office of STEM Education: Infusing Introductory Biology Courses with Higher-Order Curricula. \$6,000.
- **Lemons, P. P.** (2009-2010) UGA Office of STEM Education: Infusing Introductory Biology Courses with Higher-Order Curricula. \$8,000.
- **Lemons, P.P.** (2003-2003) Duke University Center for Instructional Technology and Arts and Sciences Committee on Faculty Research, multiple projects. \$5,445.

### SELECTED PRESENTATIONS AND WORKSHOPS

- **Lemons, P. P.** University of Maine, Center for Research in STEM Education (RISE) (February 2014) "Helping Biology Students Develop Problem-Solving Skills."
- **Lemons, P. P.**, Terry, D.R., and Herreid, C. F. (2013) Case Study Teaching in Introductory Biology: How Do Questions Impact Student Learning? poster presented at the NSF Transforming Undergraduate Education in STEM Pls Conference.
- **Lemons, P. P.** and Lemons, J. D. Society for the Advancement of Biology Education Research, Annual Meeting (July 2012) "Questions for Higher-Order Cognition: It's Not Just Bloom's."
- **Lemons, P. P.** and Lemons, J. D. American Society for Cell Biology, Annual Meeting, Education Initiative Forum (December 2011) "Challenges Uncovered: What Biologists Say About Higher-Order Questions."
- **Lemons, P. P.** and Prevost, L. # Society for the Advancement of Biology Education Research, First Annual Meeting (July 2011) "Multiple-Choice Testing and Cognition in an Introductory Biology Course."
- **Lemons, P. P.** Duke University, Department of Biology and Center for Instructional Technology, (April 2010) Biology Workshop: "When to Use Multiple Choice and When to Use Short Essays: Designing Tests That Tell Us Something Without Breaking our Backs." And Public Seminar: "Using Case Studies to Teach Science and Higher-Order Reasoning." Reynolds, J., and **Lemons, P. P.** (2009) Teaching Metacognition to Improve Critical-Thinking Skills in Introductory Science Courses, research talk presented at The SoTL Commons: A Conference for the Scholarship of Teaching and Learning.
- Reynolds, J., and **Lemons, P. P.** (2009) Teaching Metacognition to Improve Critical-Thinking Skills in Introductory Science Courses, research talk presented at The SoTL Commons: A Conference for the Scholarship of Teaching and Learning.