Application Details

Manage Application: Curriculum Innovation Award

Award Cycle:	2017
Internal Submission Deadline:	Friday, January 27, 2017 at 5:00 PM
Application Title:	The Problem Solving Studio: An Apprenticeship Environment for Aspiring Engineers
Application ID:	001369
Applicant First Name:	Joseph
Applicant Last Name:	Le Doux
Email Address:	jl200@gatech.edu
Phone Number:	(404) 661-0752
Primary Appointment Title:	Associate Professor
Primary School or Department:	Biomedical Engineering
Submission Date:	Friday, January 20, 2017
Proposal Title:	The Problem Solving Studio: An Apprenticeship Environment for Aspiring Engineers
* **Letter Writer E-mail 1:**	sroche6@gatech.edu
* **Letter Writer E-mail 2:**	broseni3@gatech.edu
* **Letter Writer E-mail 3:**	acamdzic6@gatech.edu
* **Letter Writer E-mail 4:**	skale31@gatech.edu
Letter Writer E-mail 5:	asiu3@stanford.edu

1. Description of the Innovation

I teach an entry-level engineering fundamentals course in the biomedical engineering department at Georgia Tech. This course is a major challenge to our students, and many struggle. I love teaching this course because the students come in with little understanding of what it means to think like an engineer, so it is a wonderful opportunity to have a major impact on their lives. Long ago I realized that teaching is not really about the content – that changes fast, especially in a rapidly evolving field like biomedical engineering. Rather, teaching is about motivating and mentoring students to become scholars, to help them learn new and powerful ways of thinking that will serve them well not only in their chosen field, but also in all aspects of their lives. It took me a few years to develop this way of thinking about teaching and learning. Early in my career, I used a lecture-based approach in this course. I was not satisfied with my students' engagement and learning. Inspired by the passion that one of my undergraduate professors brought to his engineering instruction years ago, I decided to apply my research skills to my teaching, to develop a better way. The result is the Problem-Solving Studio (PSS).

Problem or student learning issue the innovation addresses

The PSS approach is designed to improve student learning in engineering courses that teach students how to solve complex analytical problems, but with the often unwritten goal being to teach students what it means to *think like an engineer*. Courses such as these are common in engineering curricula, and are often taken by sophomores and juniors. They are sometimes called "middle years" courses. The National Science Foundation and others have identified the middle years' courses as a major problem in engineering education because many students struggle in them, which may contribute to some students' decisions to transfer to a non-engineering major.

One reason students struggle in these kinds of courses is they enter them with little prior experience in dealing with ill-structured, complex problems. They come to these courses with a well-practiced rote problem solving approach in which they 1) write down the known and unknown variables they find in the problem statement, 2) search for a formula or equation that uses these variables, and then 3) enter the numbers into the formula and calculate an answer. Indeed, a common lament of engineering professors is that their students persist in using ineffective plug-and-chug approaches in which they search for problems with similar surface features to the one they are trying to solve and then plug their numbers into the equations that worked for these similar problems, hoping this will lead to the correct answer. Some researchers have noted that despite an increased emphasis in the past several years on conceptual understanding and connecting concepts to problem-solving in textbooks and curricula, the plug-and-chug approach has remained prevalent. Bodner, as far back as 1992, suggested that to address this issue we must change how the curriculum is delivered. That is, if we want students to learn how to become more effective problem solvers, who do not rely on rote memorization of procedures, formulas, and algorithms to solve problems, than ***we need to design and implement more effective learning environments.***

The objective of the innovation

The purpose of PSS is to meet this challenge by creating a learning environment that is more effective than traditional approaches for teaching students how to solve difficult analytical engineering problems without resorting to rote memorization of algorithms, while at the same time developing their deep conceptual understanding of the course topics. In addition, although I began developing the PSS environment years before the flipped classroom movement took hold nationally, PSS is an excellent model for what to do with the in-class time that is freed up by instructors who flip their courses.

The learning outcomes of the intended audience

I developed the PSS approach in BMED 2210 (Conservation Principles in Biomedical Engineering), a required course for BME majors. The course has three student outcomes, each of which contributes to the Department-level ABET-accredited Student Outcomes (a) and (e), which are that students will demonstrate an ability (a) to apply knowledge of mathematics, science, and engineering and an ability (e) to identify, formulate, and solve engineering problems.

The three course learning outcomes that are specific for BMED 2210 are:

Outcome 1: Know the basics of conducting engineering calculations. This includes students being able to a) convert quantities from one set of units to another quickly and accurately, b) define, calculate, and estimate system and material properties such as fluid density, flow rate, chemical composition, fluid pressure, temperature, enthalpy, work, and heat capacity, and c) draw and label process diagrams, and use the diagrams as problem-solving tools, starting with written or verbal descriptions of problems.

Outcome 2: Comprehend concepts and principles of mass and energy conservation. This includes students being able to a) identify principles in restated form, b) describe examples of principles and state hypothesis that are in harmony with the principles, and c) distinguish between correct and incorrect interpretations of the principles.

Outcome 3: Apply these concepts and principles to the analysis of biological systems. This includes students being able to a) write and solve mass and energy balance equations for single-unit and multi-unit systems, systems with multi-component streams, systems with reactive processes, and dynamic systems, and b) calculate internal energy and enthalpy changes for fluids that undergo specific changes in temperature, pressure, phase, and chemical composition and incorporate the results of these calculations into system mass and energy calculations.

Approach taken

Summary of the approach taken

PSS is unique because of an integrated set of features that work in combination to engage students in the work of constructing knowledge through *interactive dialogues* with each other to solve difficult analytical engineering problems, in a public and shared problem solving space, while being nearly continuously observed and provided feedback by their instructor and near-peers. This is accomplished by having students work in teams of two at the same table with another team of two. The student teams and tables are stable, remaining together for most of the semester. The teams work on a large pad of paper (a desk blotter) which serves as a public, shared problem-solving space that allows in-class mentors (near peers of the students) and the instructor to observe and critique their work. The public nature of the work enables the instructor to provide students with real-time, situated feedback. In addition, it enables the instructor to tailor the challenge level to the needs of each team, such that the problem is too difficult for any one student to solve on their own, but reasonable enough that the team can solve it together, given the support that the PSS environment provides. I call this targeted adjustment of the problem's difficulty *dynamic scaffolding*. PSS provides the support students need by using a specific set of *participant structures* that govern how the instructors, in-class mentors, and students interact during class. By using these participant structures, instructors help students achieve the learning objectives.

Detailed description of the approach taken

Physical layout of the PSS room. Before I describe these participant structures, it is helpful to understand the physical layout of the room and how the participants and learning materials are organized. The first major difference one observes in a classroom setup for PSS is its physical setup. The Biomedical Engineering Department at Georgia Tech has outfitted two classrooms to support PSS. Each classroom can hold up to 48 students seated at 12 tables. All the tables and chairs are on wheels. Ideally, the furniture is configured so that each table is isolated so that there is sufficient space between the tables to make it easy for the instructor to move about the classroom and to quickly reach any student or table. There are several whiteboards distributed among the walls of the room that are magnetized so that the students' work can be posted for review and discussion. This setup allows the instructor and students to configure the room in ways they believe best supports their learning for that particular day's activities. This specific setup is not required to implement PSS. Most important is that the classroom allows the instructors to observe and critique each team's work in real time.

Students solve difficult problems. The primary purpose of BMED 2210 is to develop the students' analytical problem solving skills. It is not a design course. Nevertheless, for the most part, I give students problems that are challenging enough that the students solve only one or two problems in a typical 2-hour PSS class session. In designing a problem, I often begin with a problem from their textbook, but modify it to be more ill-structured and more complex. I make the problem more ill-structured by increasing the number of unknowns and by increasing the number of ways the problem can be solved. I steadily increase the complexity of the problems throughout the semester, using problems with longer path lengths from the initial state to the goal state of the problem and by increasing the number of relations and concepts the students need to process while solving the problems. The reduced structure and increased complexity of these problems provides students with multiple options for how to approach and solve them, which leads to robust discussions among the students and instructors.

The instructor dynamically scaffolds student learning. A key instructional challenge is to present each team, each table, and the entire class with a problem that is appropriately challenging, but not so difficult that students make little to no progress for an extended period of time. The role of the instructor is to provide support and assistance to enable the student to operate at a higher level than they could if they were working on their own. This is difficult to achieve in a traditional lecture-based course. In contrast, several features of PSS make it possible to dynamically modify in real-time the scaffolding that is provided to the students, either at the local level of an individual student-team or table, or at the global level of the entire class. I call this aspect of PSS *dynamic scaffolding*. In PSS, I can dynamically scaffold students' learning by ratcheting up or down the difficulty of a problem, by making it less or more complex or by making it less or more structured, as described above. Typically, in PSS, the instructor would begin by presenting the entire class with a problem that they believe is sufficiently difficult for the class' more advanced students. Then, the instructor assesses, in real-time, the progress that students are making on the problem to determine if, and for whom, the problem's difficulty needs to be modified. The instructor can then choose to reduce or increase the difficulty of a problem for a single team or table, or for the entire class.

PSS is powered by several participant structures. PSS enables instructors to monitor students' progress in real-time through the participant structures it creates. Susan Philips defined "participant structures" as the "ways of arranging verbal interaction with students, for communicating different types of educational material, and for providing variation in the presentation of the same material". The primary participant structure of PSS is the team of two students who problem-solve together on a publicly visible problem-solving space (we typically use 17"x22" pads of blotter paper). In most cases, one student writes on the blotter pad while explaining what they are doing to their partner. The partner who is not writing actively engages in the problem-solving process by listening carefully, agreeing with or critiquing what their partner is doing, and suggesting their own ideas about how to proceed. Every few minutes the students switch who is holding the pen. The students negotiate who holds the pen and for how long.

There are three key features of this participant structure that we believe promote learning. First and foremost, it requires students to explain and defend the approaches they take to solve the problem. Self-explanation such as this promotes learning and facilitates problem solving by helping the problem solver draw conclusions and make inferences from the problem statement when critical information is missing. Second, the two students must work together to solve the problem. This requires students to argue their points, to communicate clearly and persuasively, and to negotiate with a peer which route to take when solving the problem. Michi Chi and others have shown that this kind of "interactive dialoguing" leads to deep learning. Finally, the third key feature of this participant structure is that the team's work is publicly visible, to the other team at their table, as well as to the in-class mentors and the instructor. Other key participant structures of PSS are depicted in Figure 1. They include 1) when the pair of teams that are seated together at a table confer with each other to solve the problem; 2) when an in-class mentor (a near peer) or the instructor interacts with a team or table of students, initiated by the students or by the mentor/instructor; and 3) when the instructor interacts with all the students at the same time by facilitating a just-in-time discussion with the entire class.

Figure 1. The key participant structures of PSS. Panel A shows students working on blotter pads in teams of 2, across from another team of 2 at the same table. Panel B shows an in-class mentor, a "near-peer", working with a student team. Panel C shows the instructor mentoring a table of 4 students.

PSS assessment promotes students working together to maximize their learning. Finally, another important feature of PSS is that the work the student teams do together is not graded. Only individual work is graded, and course grades are assigned using a straight scale published in the syllabus on day one of the course. This helps create an environment in which students help each other learn and in which the students and instructors work together to help all students perform well on the graded assignments. Graded assessments include 1) weekly homework assignments that reinforce and go into greater depth the concepts and problem-solving approaches that were focused on in PSS that week; 2) weekly quizzes that focus on the material that was the focus of the previous week's homework assignment; 3) two mid-term exams; and a 4) cumulative final exam.

2. Evaluation of the Innovation

I have conducted substantial evaluation and documentation to assess the effectiveness of PSS. First, I have used an externally created, peer-reviewed, reliable and validated concept inventory for the topical matter of this course to compare student learning in BMED 2210 in the PSS learning environment versus in the traditional lecture setting. I also used an instrument that assesses the extent to which students' diagrammatic reasoning skills improve in the PSS learning environment versus in the traditional lecture-based setting. In addition, I conducted a longitudinal study that compared the grades students earned in the follow-on course for BMED 2210, which is BMED 3210 (Biotransport). Finally, I compared students' evaluations and comments in the end of course CIOS surveys from before and after I implemented the PSS approach. The evaluation of PSS is on-going. My current focus is to study the impact of PSS on students' approaches to learning, a project that is funded by the NSF (2 years, $250,000). Below I share a representative subset of the data I have collected on PSS.

Dataset 1: The conceptual understanding of PSS students improves more than with students in lecture-based versions of BMED 2210. In this study, I used Shallcross' Mass and Energy balances concept inventory (CI) to compare the changes in students' conceptual understanding of the course's major concepts that occurred during the fall 2013 semester. Students took the CI two times, during the first week of the course and during the last week of the course. One hundred and twenty-seven students participated in the study: thirty-two of the participants were enrolled in the PSS version of the course and the remaining ninety-five students were enrolled in two different sections of the lecture-based version of the course, taught by two different experienced professors. The results are shown in Table 1.

Table 1. Concept inventory scores of BMED 2210 students (Fall 2013)

Performance measure	**PSS**	**Lecture**		
Number of students who completed but pre- and post- concept inventory	32	95	**Fold difference**	**p-value**
Pre-CI scores	9.00 +/- 3.48	8.46 +/- 3.22		0.40
Post-CI scores	13.15 +/- 3.43	10.08 +/- 3.75		0.000047
Change scores	+4.15	+1.62	2.6	0.0031
% of change scores >= 9	19	5.3	3.6	
% of change scores >= 6	44	12	3.8	
% of change scores were <=0	22	33	0.67	

The data show that all the students entered BMED 2210 with the same conceptual understanding of the material, as measured by Shallcross' CI instrument ($p = 0.40$). However, PSS students finished the course answering, on average, 13.15 of the 22 questions on the CI correctly, an average improvement of 4.15 correct answers. The scores of students who took the lecture-based course improved from 8.46 out of 22 at the beginning of the semester to 10.08 out of 22 at the end of the semester, for an average change score of 1.62 ($p = 0.0031$). This change score is 2.6-fold lower than the change scores of students who took the PSS version of the course. Table 1 also shows that the percentage of students who saw dramatic improvements in their CI scores (>= 9 and >=6) was much higher in the PSS section than in the lecture-based sections.

Dataset 2: PSS students' engineering diagramming skills improves more than students in lecture-based versions of BMED 2210. In collaboration with a research scientist, Alisha Waller, I developed a diagramming challenge that assesses the ability of students to generate an engineering diagram from a verbal problem statement. The instrument is based on our prior observations that students, when presented with the challenge, create one of four types of visual representations that are either 1) text, 2) a single picture, 3) multiple unconnected pictures, or 4) unit processes connected by flow streams. The 4th category of representations is most similar to professional engineering diagrams. A key-learning objective of the course is for students who complete the course to be able to generate category 4 diagrams from a written description of a process. Therefore, to assess the impact that BMED 2210 has on students' diagramming skills, we used this challenge to assess students at the beginning of the course and at the end of the course. These studies were carried out in the 2013-2014 school year with students who took BMED 2210 in the PSS learning environment or in the traditional lecture-based environment.

At the beginning of the course, only 41% of students (20 of 49) in the lecture-based BMED 2210 course represented the process with the desired category 4 unit-diagram representation. Similarly, only 41% of students (23 of 57) in the PSS-based BMED 2210 course represented the process with the desired unit-diagram representation. In the end-of-course diagramming challenge, 63% of students (31 of 49) in the lecture-based BMED 2210 course used the desired unit-diagram representation, whereas 100% of the PSS students (57 of 57) used the desired unit diagram representation. These results show that the students entered BMED 2210 with similar diagramming skills, but by the end of the semester, PSS students' diagramming skills were more advanced than students who took the lecture-based course.

Dataset 3: PSS students' grades in the follow on biotransport course (BMED 3300) are higher than the grades of students who took a lecture-based version of BMED 2210. Finally, in collaboration with John Leonard (COE), we analyzed the grades of students who took BMED 3300 with one instructor (Ross Ethier) during the spring and fall semesters of 2013. The data are shown below in Table 2.

Table 2. Grades of BMED 3300 students as a function of their BMED 2210 learning environment

Spring and Fall 2013	Took PSS-based BMED 2210	Took lecture-based BMED 2210
Number of students	51	116
Course grade (mean)	57.3	48.4
Course grade (s.d.)	17.2	16.7
p value	0.0020	

These data show that students who took BMED 2210 in the PSS learning environment on average earned a course grade that was 8.9 points higher, on a scale of 100, than students who took BMED 2210 in a lecture-based environment (p = 0.0020).

Dataset 4: My CIOS score for "Instructor. Overall effectiveness" question increased significantly after switch to the PSS approach. Finally, my end of course evaluations significantly improved the first semester I switched to the PSS approach in the spring of 2008. See Figure 2. The general trend is that my CIOS scores on this question have steadily improved such that the last 3 semesters I have taught the course, I have earned a score of 4.8 each time. This is remarkable given that BMED 2210 is a challenging, required analytical engineering course. In addition to the strong CIOS scores, each semester there are numerous positive comments about the PSS environment

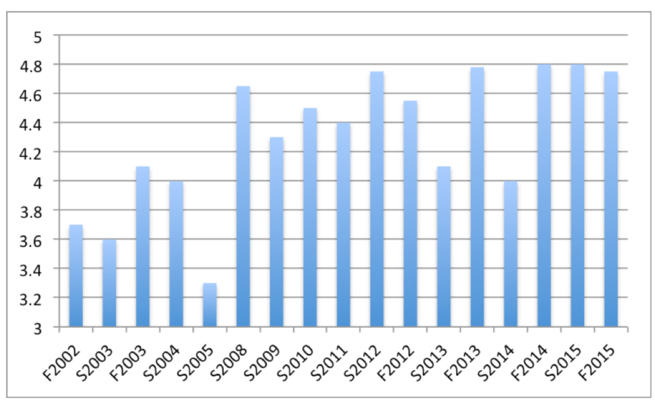


Figure 2. CIOS scores for the "Instructor. Overall effectiveness" question for every semester I have taught the course.

that are not easily summarized. Here I share some comments from last semester's (Fall 2015) evaluation that illustrate some of the key features of PSS. These comments are typical of those students make when asked to comment about the course's best aspect:

> "PSS was amazing. Very supportive and helpful in grasping concepts beyond memorization and regurgitation"

> "I really enjoyed the PSS setting. It caused me to be more engaged during class. Having peers working on problems with me was helpful because they were able to explain concepts that I was unfamiliar with"

> "We got to work through problems with each other in order to facilitate our own understanding and get immediate feedback from TAs if we didn't understand something or needed help"

3. Description of the potential for others to adopt or adapt the innovation

The PSS approach has excellent potential to be adopted and adapted by others. I have taken several steps to help assist and promote the use of the PSS environment elsewhere. I have shared the PSS approach at several national conferences, including BMES (2012), FIE (2012, 2014), ASEE (2013), AAC&U (2012), and FOEE (2012). I have also shared the approach at several functions in the Georgia Tech community, including at an IPaT townhall meeting (2011), the C21U launch event (2011), at two GT STEM Education Research Expos (2013 and 2014), and at a "flippers" boot camp hosted by the College of Engineering in 2014. In addition, GT's Professional Education department created a video that depicts the PSS environment that was entered into the NSF's Teaching and Learning video showcase event in 2015. The video can be viewed here: http://tinyurl.com/z7s3sp8. In addition to these more formal sharings of PSS, many graduate students and professors have visited my class to observe PSS in action. Finally, I recently wrote my first paper that describes the PSS learning environment in detail, which was published in the Winter 2016 issue of *Advances in Engineering Education*, a publication of ASEE (the American Society of Engineering Education).

In part due to these outreach efforts, the PSS approach and approaches inspired by it, have recently been adopted by others at Georgia Tech. Several BME professors have adopted the PSS approach, or variations of it, in their courses in the last two years. In the Fall of 2013, Professor Ethier (BME) began using the PSS approach to teach BMED 3310 (Biotransport), and later repeated and expanded its use, with good success, using a team-teaching approach with Dr. Melissa Kemp. Beginning in 2014, Dr. Eberhard Voit (BME) began using the approach, in collaboration with a team of professors, to teach BMED 3520 (Biomedical Systems and Modeling). And this year the BME department committed to using PSS to teach all sections of BMED 2210 (~ 400 students per year will take the PSS version of the course). To date, five BME instructors, Dr. Johannes Liesen, Dr. Linda Harley, Dr. Gabe Kwong, Dr. Ed Botchwey, and Dr. Maysam Nezafati have been trained in how to teach using PSS. The PSS approach has also influenced learning environments outside of BME. For example, Don Webster, who observed the PSS learning environment during the fall semester of 2012, employs a similar approach to teach two Mechanical Engineering core courses: fluid mechanics and dynamics. Most recently, this semester CTL has expressed an interest in working with me to recruit and train a Statics instructor to use the PSS approach. So, clearly, the approach can be adopted and is being adapted by others.

Resources required

A full implementation of PSS benefits from a few resources:

1. The physical layout of the classroom should signal to the student that they are the center of attention, not the professor. The tables and chair should be reconfigurable to give a sense of possibility and energy, and to allow the professor to arrange things as needed on any particular day to maximize learning. Also, it helps to have multiple whiteboards throughout the room so the instructor can lead just-in-time discussions about the material the students are struggling with as they problem solve.

2. Each student team needs a desk blotter pad (17 x 22 inches) to use as a shared and public problem solving space. It is also beneficial to have sharpie pens, or their equivalent, available for students to use in multiple colors so they can generate easy to understand diagrams and solutions. It is possible to use portable whiteboards to reduce costs from semester to semester, but it is sub-optimal because the problems we work on are too long to fit on a single whiteboard. In addition, the permanence of the blotter pads allows the students to flip back to see their work earlier in the semester. Students often feel accomplished and motivated when they see how far they have come.

3. Another key resource for effectively carrying out PSS are well-designed problems. Good PSS problems target specific misconceptions and skills that most students struggle to master, and that enable the instructor to easily dynamically scaffold the students (adjust its difficulty). Creation of good problems takes time and is helped by instructors who have good pedagogical content knowledge. Once effective problems are created, they can be re-used each semester to good effect.

4. Implementing PSS effectively take practice managing dynamic scaffolding and just-in-time discussions. It is helpful for instructors who are new to this approach to observe or apprentice with an experienced instructor.

Georgia Tech College of Engineering

College of Engineering
Office of the Dean

January 25, 2016

Esteemed Awards Committee:

I am writing to offer my unconditional support for the nomination of Dr. Joseph (Joe) Le Doux for the CETL Curriculum Innovation Award. I cannot think of a person at Georgia Tech more deserving of this award that recognizes a faculty member dedicated to improving the quality of our students' education. I have observed Joe over the past eight years work to systematically design a learning environment for engineering that is informed by what we know about learning. He calls this the *Problem Solving Studio (PSS),* a learning set-up that goes way beyond what might be called "active" to embrace the notion that learners need to actively construct their knowledge through interaction with other students, undergraduate TAs and faculty. In the PSS, he has created a community of learners and problem-solvers who take on significant engineering problems each class that force them to apply what they have learned, identify what they need, take risks, fail, recover and succeed, all within a supportive learning environment. The current features of this environment have been iteratively developed over time using what is very close to the engineering design process. In the learning sciences, we call these *design experiments* in which the faculty-researcher conducts an analysis of the problem and the metrics for success, develops a prototype based on learning fundamentals, runs a prototype, collects data and redesigns the learning environment based on the data. This is what might be understood as engineering the classroom.

Joe's experiments began when he faced significant student learning challenges in his Principles of Conservation: Mass-Energy Balances class in BME. Every semester, the students divided into three groups: quick learners, strugglers who experienced a tipping point and then succeeded and strugglers who never experienced a tipping point (even in the third term trying to pass). No matter what he did in class, no matter what kind of demonstrations he provided, these groups always materialized. A less committed teacher would have said, "Well, that's the student's problem. If they studied more, anyone can get this. It's easy." Not Joe. He began his redesign my moving his class into the design studio, which offered a space that communicated to the students that this was not going to be a writing-equations-on-the-board engineering lecture class. The tall four-person studio desks immediately changed the way students interacted with each other and with him. The room caused students to work differently and he found himself having authentic conversations with the student groups. Using today's jargon, Joe flipped his class way before it became fashionable. Time in class was devoted to student teams working on problems and time out of class devoted to reading the book and learning form the examples. Over time, he has added a significant feature---large blotter pads that serve as the workspace for student pairs

Atlanta, Georgia 30332-0360 U.S.A.
WEBSITE: http://www.coe.gatech.edu
PHONE 404•8
FAX 404•8

while offering visibility to the TA's and Joe as they cruise through the room. This visibility allows him to "see" where the teams are generally and to give mini-lectures driven by the data he has visually collected. Using self-determination theory or a theory of motivation, he has continually added additional features designed to promote student autonomy, confidence and engagement. Most recently, he has brought the notion of "grit" to the students and asks them continually to assess their own grit or perseverance in the face of difficulties. This PSS model has been so successful in BME that all sections of this class now utilize this approach and additional faculty each semester are being apprenticed to this socio-cognitive approach to learning. In addition to designing this environment, Joe has conducted rigorous studies as well which he has reported on at conferences and will soon appear in *Advances in Engineering Education.*

Joe is committed to enhancing the quality of learning and instruction for all GT students. He is highly deserving of this CETL recognition. I urge the committee to recognize his significant efforts with this award.

Sincerely,

Wendy C. Newstetter

Wendy C. Newstetter PhD
Director of Educational Research and Innovation

Wallace H. Coulter Department of Biomedical Engineering
Georgia Tech College of Engineering and Emory School of Medicine

January 18, 2017

Dear Awards Committee,

I enthusiastically support Professor Joe Le Doux for the Georgia Tech Curriculum Innovation Award. I have been Joe's colleague for several years and have observed his work as Interim Department Chair and as a fellow professor in the Wallace H. Coulter Department of Biomedicine Engineering. It is because of Joe's pedagogical innovations in BMED 2210, and the subsequent transformative effects it has had on our biomedical engineering (BME) undergraduate curriculum, that I believe he is most deserving of this award. I will first provide here some background on this course, then describe the innovations he has pioneered, and finally share the current status of how his innovations are transforming our curriculum.

Virtually every engineering major has a "gateway" course that focuses on fundamentals for that discipline. BMED 2210 is that course for BME. These are challenging courses for students who up to that point have only had experience solving math and science problems. Transitioning to solving engineering problems is challenging for both the students and the faculty teaching these courses. Our faculty have struggled with this course since our curriculum was first designed nearly 15 years ago. Actually, we had already overhauled this course twice since its first offering in 2002 (i.e. previously BMED 3200 and later changed BMED 2200) trying to find the best combination of curricular topics and pedagogical formats.

In 2008, Joe began to develop his Problem Solving Studio (PSS) approach in BMED 2210, around the same time that Sams and Bergmann were first experimenting with the flipped classroom. PSS may seem similar to a flipped classroom to the casual observer, which is when traditional lectures are replaced by on-line lectures that students watch outside of class. But a closer look reveals that PSS refers to how time spent in the classroom is structured. The students' primary activity in PSS is solving difficult engineering problems, work which takes precedence over the lecture as the main method for teaching. The importance of creating engineering diagrams and using them as thinking tools is heavily emphasized. Student work is carried out in a public space so that it is visible to other students and the instructor, and the instructor frequently enters into a discussion with them about their work. In addition, older students, who performed well in the course in a prior semester, serve as in-class mentors and roam the room to assist the instructor in providing feedback to the students.

This is an apprenticeship model of learning, in which the novice learns by observing the expert undertake a specific task, and then attempts the same task while getting feedback and guidance. In PSS, the students are engaged in a cognitive apprenticeship with their instructor because the tasks that are being learned are intellectual, not physical, in nature. Joe's research on the impact of PSS on student learning, which has been supported by two NSF grants, has demonstrated that it has significantly improved the students' conceptual understanding of the material. Joe has begun to train his colleagues on the use of PSS. As of the fall semester of 2016, all sections of 2210 began employing the PSS approach. To date, five different professors other than Joe have taught their section of BMED 2210 using the PSS approach at least one time.

In addition, his demonstrated success has inspired several faculty to adapt PSS to their courses, most notably myself in BMED 3310 (Biotransport), and professors who teach BMED 3520 (Biosystems Modeling). Clearly the impact of his work extends well beyond his own classroom. Joe recently published an overview of PSS in the Winter issue of this year's *Advances in Engineering Education*, and I expect that his work will impact student learning at other universities as well.

In summary, Joe's innovations are not only aiding student learning in his classroom, but also those of his faculty colleagues at GT and more broadly. He represents a rare breed of engineering faculty who conducts engineering education research and puts it into practice for the benefit of students. He is a true leader in this area, and I am grateful to have him as a colleague. I endorse his Georgia Tech Curriculum Innovation Award nomination in the strongest possible terms.

Sincerely,

C. Ross Ethier, Ph.D.
Wallace H. Coulter Interim Chair
Georgia Institute of Technology and Emory School of Medicine

C. Ross Ethier
Interim Chair, Wallace H. Coulter Department of Biomedical Engineering
Lawrence L. Gellerstedt, Jr. Chair in Bioengineering
Georgia Research Alliance Eminent Scholar in Biomechanics and Mechanobiology

Georgia Institute of Technology
The U.A. Whitaker Biomedical Engineering Building
313 Ferst Drive, Atlanta, Georgia 30332-0535
404.385.5038 • ross.ethier@gatech.edu • www.bme.gatech.edu

Emory University School of Medicine
Health Sciences Research Building
1760 Haygood Drive, Suite W 242, Atlanta, Georgia 30322-4600
404.727.9827 • ross.ethier@gatech.edu • www.bme.emory.edu

1/13/2017

To whom it may concern,

My name is Anela Holdaway and I am currently a senior at the Georgia Institute of Technology pursuing degrees in Biomedical Engineering and Physics. I have had the opportunity to take Dr. Joseph Le Doux's class *BMED 2210: Conservation Principles in Biomedical Engineering* in the Spring of 2016. After completing numerous undergraduate courses in the past four years, I can say without reservation that Dr. Le Doux's class was one of the most impactful educational experiences I have had. The positive influence of the class stems from not only having a professor that was engaged and thoughtful, but also from the unique problem-solving studio feature.

In the problem-solving studio, I had the opportunity to apply the knowledge gained from the weekly textbook readings and traditional lecture. Many of my other classes provided individual based homework as the main form of practice for the principles taught in lecture and readings. While this class also featured homework, the practice in the studio was different in that it involved hands on problem solving within groups. When I was struggling to understand a concept or to find an appropriate solution, I would consult my peers for advice. On the other hand, I was also a source of knowledge and guidance for my peers when they found particular problems difficult.

The ability to interact with others while working through problems was one of the first experiences I had with being an effective engineer. In engineering a main component of what makes a person successful is their ability to solve complex problems on an individual level, as well as, a team member. Thus, the studio has had an essential role in my engineering education in that it has better prepared me to solve problems in a group with other engineers. The ability to work well in a group has also shown to be a valuable skill in my other biomedical engineering classes, as well as, classes that have involved group work with cross-disciplined peers and professionals.

Another unique feature of the problem-solving studio was the ability to receive real-time feedback from the professor, teaching assistants, and other students. I did not have to save my questions about the problems I was struggling with until office hours, nor did I have to wait until I received my homework assignment back to know what I had done wrong and did not properly understand. Instead, I could receive feedback in a manner that would help me progress in not only the problem I was currently working on, but also within the next set of problems and concepts.

The problem-solving studio aspect of Dr. Le Doux's class has allowed me not only to gain a stronger grasp on conservation principles through real-time feedback, but it has also taught me invaluable skills in team problem solving. I have applied the knowledge and skills gained from this class into all of my subsequent undergraduate experiences. It is my hope that through my personal rendition it has become clear how effective and impactful the problem-solving studio is within a formal engineering education.

Sincerely,

Anela Camdzic Holdaway

November 19, 2016

Dear Selection Committee,

When I began my freshman year at Georgia Tech in Fall 2010, I was very unsure of my decision to pursue a degree in Biomedical Engineering. Having a learning disability, I struggled through my first 2-3 years at Georgia Tech. I was on Academic Probation and I honestly believed that I wasn't smart enough or "cut-out" to be a student at Tech. In Spring 2015, I enrolled in BMED 2210 with Dr. Le Doux. I could have never imagined the impact that his course would have on my academic and personal life. Today, I am honored to have been given the opportunity to write this letter of support for Dr. Le Doux.

Nearly every course I've taken as a college student entailed long and unenthusiastic lectures of 50-150 students, supplemented with even less motivating recitations or labs. Such a structure is not an ideal learning environment for any student, much less for a student with learning disabilities. On the first day of class, Dr. Le Doux introduced two terms that I had never heard before: *deliberate practice* and *scholarly grit*. Referencing a few research articles, he described that practice is the key to becoming an expert at something. But, how much you practice is not enough to succeed. Exactly how you practice - the quality of your practice - is equally as important as how much you practice. One such article showed that "innate talent" is less relevant in becoming an expert, and in fact, deliberate practice is far more critical in demonstrating expert-level performance. I have never had a professor begin a course in this way; making bold claims and validating them with research. He said that the combination of deliberate practice, optimism, and understanding that learning takes time, is what he calls *scholarly grit* - a term that will forever be in my daily vocabulary.

Dr. Le Doux then introduced the Problem Solving Studio (PSS). He explained that in order to achieve the highest level of expertise as an engineer, we must learn to think like engineers - and that the PSS would help us learn this abstract and complex way of thinking. The learning environment he created gave every student the opportunity to exercise and train their minds in the process of solving a problem until problem-solving eventually became a habit - allowing us to develop the habits of the engineering mind. His teaching methods gave me a set of skills that no other course has offered. Like a textbook, most courses are heavily focused on the course topic. BMED 2210 was more than just learning about Conservation Principles. It was about the process of solving problems, which is useful in any and every class.

While it was incredibly challenging and tested me on multiple different levels, there was never a day that I did not *want* to go to class. I *always* wanted to partake in the PSS - we all did. I believe that a huge part of the reason I felt the need to attend is because of the way the PSS is designed. Every day in class, I sat with my partner at a table with another set of partners. Dr. Le Doux usually began by introducing a topic and then giving us one problem to solve with our partners. When we could show that we had successfully completed the problem and fully understood our own solutions, we were given another problem. This sort of structure holds every student accountable for their attendance because if someone fails to attend class, their partner is left without a partner to solve the problems. But if a student has a valid reason for not a attending class, their partner still has the rest of the group to help them for the day.

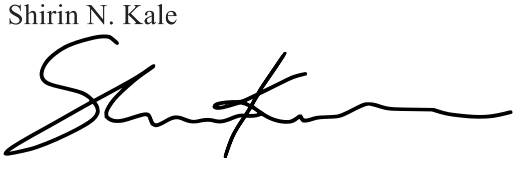
The PSS exposed me to other students' ways of problem-solving. Giving me the opportunity to listen to and observe the different ways of thinking of my partner and group was the most powerful and useful part of the PSS. The design of the PSS forced me to think out loud and communicate my thought process - from start to finish - to my partner and vice versa. This gave me the opportunity to see and hear my partner's approach to a problem, but also gave me the opportunity to improve the way I communicate my knowledge with others - sharpening my knowledge of the topic and my communication skills. One problem at a time, we all adopted the best aspects of each other's problem-solving process. As I write this letter, I now realize that the PSS is just genius - dynamic and also fluid. If I were to create a graphical representation of learning (y-axis) with time (x-axis) in a typical college course over one semester, it would have many local maxima and minima - spiking during lectures, drastically falling on weekends or holidays, and eventually reaching the global minimum after taking the final exam. But the same graphical representation applied to the PSS would look much smoother and much more linear - reaching a maximum upon taking the final exam. It actually made the class useful; the material I learned stayed with me far beyond the final exam. It's 2016 and I still use the skills I learned in the PSS.

While the PSS made for an engaging and fun class, PSS itself was not always fun. It was incredibly hard, which made it incredibly frustrating. There were times when my partner and I spent an entire class on one problem. Dr. Le Doux refused to give us the answer. He walked around to each group and gave them custom feedback and guidance. He never spoon-fed the answer (even if that meant spending an entire class on one problem) because the answer is only minimally relevant to what he is trying to achieve with the PSS: innovative thinkers who can solve any problem thrown their way. And just when I felt like nothing was making sense to me, there was a magical moment when everything just clicked. Why? Because I came to the solution myself. Those moments made all of the frustration worth it. It was by far the most rewarding feeling, which pushed me and motivated me to learn more. This is the beauty of the problem solving studio.

It was difficult for me to *not* be inspired to be a better student and learner. My performance in ALL of my classes sky-rocketed. I went from being on Academic Probation the previous semester, to making a 4.0 that semester with 17 credit hours (and working in a research lab). This class instilled so much motivation and inspiration in me as a person. Learning became fun. "Impossible" tasks turned into interesting challenges I sought after. I worked relentlessly hard and succeeded because of the techniques I was learning in the PSS. I can't exactly differentiate between the PSS and Dr. Le Doux. As a learning environment, the PSS is motivating and inspiring - it embodies many of the same qualities as Dr. Le Doux. It is the reason why I love learning. Because Dr. Le Doux deviated from traditional teaching methods, I was pushed far past the point I once thought was my limit. I don't use words like "impossible" and no longer believe that I have limitations. My life completely changed after partaking in the problem-solving studio. It is the reason why I confidently and frequently say "Give me a problem and I will solve it. Any problem. I will solve it."

It's clear to me why Dr. Le Doux deserves this award: he is the epitome of a true educator. It is so easy to see how much he cares about the quality of our education and how hard he worked to develop and refine the PSS in many iterations. His passion for teaching is an invaluable gift to my peers and I. We all have a tremendous amount of respect for him. It is this passion that constantly drives him to improve his own teaching methods. It is this desire that led to the development of the PSS. He is revolutionizing the way we learn and teach BME courses. I can only hope that every student has the chance to experience what I have. In fact, *not* giving every student this caliber of education is an injustice. If we can replicate this environment in all classes, there is no limit to how far we can go as an institute. With this quality of education, Georgia Tech will produce not only the smartest engineers, but also the largest quantity of innovative thinkers; the game-changers - the type of passionate young professionals who end up changing the world. We are Georgia Tech. We have always and will always strive to be better. But being "better" means having *scholarly grit*. And I am confident that with *deliberate practice*, every professor at this institute can master this art of teaching.

Sincerely,
Shirin N. Kale



Biomedical Engineering | Spanish
Georgia Institute of Technology

Monday January 23, 2017

GT Curriculum Innovation Award Committee

Dear Committee Members:

I am writing in support of Dr. Joseph Le Doux's nomination for Georgia Tech's Center for the Enhancement of Teaching & Learning Curriculum Innovation Award. Dr. Le Doux was my most influential professor while at Georgia Tech. He created a unique and powerful learning environment that inspired me to think outside the box, to become a more independent learner and to learn beyond the classroom.

I first came to know Dr. Le Doux during my second year at Georgia Tech when I took BMED 2210: Conservation Principles in Biomedical Engineering, my first course in the BMED curriculum. The first day of class, Dr. Le Doux had us sit in groups around tables and explained how we would never have a lecture, instead class would be a problem solving studio (PSS). He would use problem-based learning for us to gain the skills and capabilities to approach not only problems in the classroom but also in the real world. I had heard the rumors of how BMED 2210 was one of the most difficult courses in the curriculum and enrolling in a class with a radically different "lecture" structure made me even more anxious. My experience turned out to be the exact opposite. As the semester progressed, I was surprised at how effective the PSS environment was in helping me understand and apply the class's core concepts. This was possible thanks to Dr. Le Doux's guidance, the support of the very dedicated teaching assistants, and the immediate in-class feedback when working in problems and collaborating with classmates. Dr. Le Doux's methodology helped me see how I, as an engineer, was capable of breaking down a large and complex problem into small and simple digestible chunks not only as a BMED 2210 student solving 2210 problems but as an engineer solving any kind of problems outside the class and Georgia Tech. If I had to rename the class, it would be BMED 2210 Learning To Think Like An Engineer.

One unique feature of the PSS was that we had stable teams of two in which we worked with the same person, each day, on large pads of paper to solve engineering problems. Each PSS day would be dedicated to understanding thoroughly a concept through solving problems. In the beginning, I disliked working in teams. My partner tended to catch on things more quickly and it was often harder for me to keep up. I kept feeling behind. However, this helped me change the way I approached class. It wasn't like any other regular lecture where I could simply come to class unprepared and just listen to lecture, go home, and return the next day to sit-in on another lecture. Instead, I had to become an active self-learner. I had to keep training my skills inside and outside of class. As the weeks progressed, not only did I learn to work better with my classmates but also became more independent and self-directed.

Another benefit from working in groups during the PSS environment Dr. Le Doux created was that I not only learned by doing (working on problems with my partner) but also learned by teaching. Leading a solution to a problem while working in a team means that you have to communicate and explain effectively your solution to someone else. It helped me see the intellectual challenges of transmitting new concepts to others and the merits of being able to understand the material at a deeper level.

In a short time, the PSS environment allowed me to gauge my level of understanding and find my gaps in knowledge to fill-in. It was effective in doing this through a couple of factors:

it exposed us to a breadth of problems we worked in class and problems we did for homework, and, in my opinion, the most valuable, the PSS gave us immediate feedback when working through problems in class. During PSS, teams would be tasked with attempting to solve a problem. Dr. Le Doux and the teaching assistants would walk around the teams to provide us with feedback and correct any misconceptions we had. Sometimes the final answer is much less meaningful than the process to arrive there.

Towards the end of the semester Dr. Le Doux came to lecture with a popcorn machine and made popcorn for the class. While we enjoyed the popcorn, Dr. Le Doux asked us a question, “What are the ideal conditions to make the tastiest popcorn?”. Despite being a bonus project, his enthusiasm encouraged the entire class to attempt at finding that ideal temperature. We had never learned about popcorn in the class! What was tasty popcorn? What did steam tables, mass and energy conservation principles have anything to do with popping corn kernels? These are the kinds of concerns and questions I would have had prior to taking BMED 2210 with Dr. Le Doux. After experiencing the PSS environment, I had learned to sketch my own path to approach this kind of open-ended questions. Dr. Le Doux created one of the most powerful learning environments I have experienced, it prepared me to approach other open-ended projects in subsequent classes such as Biotransport and Senior Design, as well as in personal academic research endeavors.

It has been almost five years since I took BMED 2210 as an undergraduate with Dr. Le Doux at Georgia Tech. I am now a graduate student at a much smaller private university. I have experienced a breadth of teaching styles and class types but the memories of the PSS environment and Dr. Le Doux’s passion for teaching are incomparable. While BMED 2210 was a relatively large class (>30 students) compared to those at my current institution, Dr. Le Doux was able to create an environment where a large class felt like a tight-knit group, where collaboration and teamwork, open discussions and self-learning were pervasive. Another factor that contributed to this was Dr. Le Doux’s approachability as a professor. His office hours were always very welcoming and encouraged. He would stay as long as a student needed help and would reach out even when you didn’t know you needed a hand.

Dr. Le Doux is an excellent candidate for the Teaching & Learning Curriculum Innovation Award. He has created a powerful and unique learning environment that is helping students learn to think like engineers, and even more important, to learn how they learn and how they can monitor and improve their approach to learning. It is my sincere belief that Dr. Le Doux provided a springboard for me to succeed as an engineer at Georgia Tech and beyond. If I can answer any questions or be of further support, please don’t hesitate in contacting me.

Sincerely,

Alexa Siu

Alexa Siu
Mechanical Engineering, Stanford University
B.S. Biomedical Engineering (2015), Georgia Institute of Technology
afsiu@stanford.edu