



## **Green Plastics Laboratory by Process Oriented Guided Inquiry Learning (POGIL)**

**Dr. Spencer S Kim, Rochester Institute of Technology (RIT)**

Dr. Spencer Kim is an Associate Professor in Mechanical and Manufacturing Engineering Technology Department (MMET) at RIT, and serves as Associate Director of American Packaging Corporation Center for Packaging Innovation at RIT. He previously worked in the semiconductor industry. Dr. Kim, as a PI or Co-PI, received grants and sponsorship from NSF, SME, SPE, universities, and industries. In 2009 and 2013, he was nominated for the Eisenhart Award for Outstanding Teaching, RIT's premiere teaching award at RIT. Dr. Kim has directed numerous undergraduate research projects and several students won the first place in the undergraduate and graduate research competitions at the 2012 and 2013 GPEC (Global Plastics Environment Conference; Division of Society of Plastics Engineers).

**Dr. Sunday O. Faseyitan, Butler County Community College**

# Green Plastics Laboratory by Process Oriented Guided Inquiry Learning (POGIL)

## INTRODUCTION

Sustainability, industrial ecology, and green chemistry are guiding the development of the next generation of materials, products, and processes. Natural and bio-based materials are emerging as a viable alternative to petroleum-based plastics, especially in both automobile and packaging applications. For example, a major problem in maintaining a healthy environment is waste disposal. Petroleum-based plastics were developed to provide durability and resistance to various forms of degradations due to fungi and microbial agents.<sup>1-4</sup> They are a part of our everyday lives. According to the Society of Plastics Engineers (SPE), over 200 million tons of plastics are manufactured annually around the world. Of that, 26 million tons are manufactured in the United States. The Environmental Protection Agency (EPA) reported in 2003 that only 5.8% of plastics manufactured in the United States are recycled, although this number is increasing rapidly.<sup>5</sup>

One of the most important subjects in the fields of engineering and engineering technology is manufacturing. Manufacturing involves a complex system of materials, machines, and people. Most subjects in the manufacturing curriculum focus on teaching the fundamentals of current materials (i.e., metals, ceramics, composites, and petroleum based plastics) and processes; however, few prepare students to work with a broad range of new materials, particularly green materials (such as green nano-materials, biodegradable polymers and plastics, and ecofriendly-composite materials) in advanced manufacturing technology. Furthermore, the current approach to teaching materials science does not appeal to students studying new manufacturing processes and systems for green plastics manufacturing technology (GPMT).<sup>6-9</sup>

The higher education community has strived for reforming the undergraduate STEM education so that traditional lecture-based instructions and laboratory exercises are transferred to more student-centered learning formats. Innovative approaches, such as student-centered, active learning, peer-led team learning, process-oriented-guided-inquiry-learning (POGIL), project-based learning (PBL), and other educational approaches have received increased attention within the educational communities.<sup>10-15</sup>

Process-Oriented-Guided Inquiry-Learning (POGIL) adapts guided inquiry approach, which is composed of a learning cycle of exploration, concept invention, and application in learning. The guided inquiry approach uses carefully designed materials to guide students to construct new knowledge.<sup>15</sup> POGIL is a student-centered strategy; students work in small groups, with individual roles assigned to ensure that all students are fully engaged in the learning process.<sup>15</sup> For example, POGIL is designed to replace traditional lecture-only methods by encouraging students to discuss course materials, rather than listening to the instructor. Particular approaches may be suitable to the students' and audience's specific characteristics, facilities, instructional goals, personal preferences, and educational resources.<sup>8,16,17</sup> Recently, many studies reported the

effectiveness of POGIL-based laboratories in chemistry and bio-sciences education.<sup>14-16</sup> However, there is no study to design and develop the POGIL laboratory practices in green plastics manufacturing technology (GPMT).

One of the goals for the NSF project is to develop a laboratory course for teaching undergraduate students in polymers selection and testing, in the engineering technology curriculum, using pedagogical approaches of guided-inquiry. This laboratory course characterizes and evaluates polymers and bio-plastics by ASTM and ISO standards. We emphasized analyzing experimental results and preparing professional-quality laboratory reports after students completed the assigned experiment. The POGIL approach utilizes the carefully designed materials in order to guide students to construct new knowledge in various activities in the classroom and laboratory.

We developed the POGIL lab manual and laboratory practices on how polymeric materials are to be evaluated and the characterization for green design by the POGIL approaches. The new approaches rely on inquiry-based, student-centered laboratory practices that enhance learning skills while insuring content mastery in both the polymers selection and testing for engineering design. Through guided-inquiry experiments, students can gain knowledge and skills in order to improve their critical thinking ability in polymeric materials selection for engineering design.

## **DESIGN OF THE CURRICULUM FOR GPMT EDUCATION**

Manufacturing technology is integrally tied to advancements in materials science and technology. Materials science and technology have played a critical role in the technological evolution of our society, from structural steels to optoelectronics and robotics technology. We have enhanced the five current core courses within the current project (NSF AWRARD No.: DUE- 1044794): that is, materials technology, mechanical engineering technology lab, plastics processing technology, solid modeling and design, and robotics in manufacturing. Also, we established an intensive undergraduate research program for co-op students in the manufacturing and mechanical engineering technology programs. Therefore, these improved courses deal with more complex materials systems and new manufacturing technologies: such as nano materials technology, green materials and manufacturing, testing and characterization, sustainability, environmental technology, solid modeling, and robotics using the proposed instructional strategies.<sup>6-9</sup>

The new GPMT curriculum is to be utilized by the new, improved approach of “Process-Oriented Guided Inquiry-Learning” (POGIL), a research based learning environment where students work in learning-teams to acquire knowledge and develop an understanding through guided inquiry for undergraduates in the manufacturing and mechanical engineering technology programs (MMET) at Rochester Institute of Technology (RIT). The students can acquire key processing skills as they learn the discipline’s content. Hands-on practice is critical to students’ willingness to implement new instructional strategies into the classroom activities. Therefore, the team-based research projects will be designed to provide exposure to green plastics technology by the proposed approaches of POGIL.<sup>6-9, 18</sup>

The primary approach of the curriculum design for this NSF project is to transform the materials and manufacturing curriculum utilized by the new instruction model and learning modules, so that students will be well prepared to step into jobs in green plastics manufacturing technology. The development and improvement of the materials and manufacturing curriculum have been

presented in the ASEE conferences and other conferences curriculum according to the instructional model, curriculum design and strategies. Table 1 summarizes the key strategies for the design, and development of POGIL-based instruction and laboratories.

**Table 1: Design of the POGIL-based Lab for “Materials in Engineering Design Lab”**

	<b>Description</b>
<b>Old lab course structure</b>	Students characterize polymers, ceramics, and composites by performing tests of mechanical and processing properties according to ASTM and ISO standards. Emphasis is placed on analyzing experimental results and preparing professional-quality laboratory reports
<b>Innovation and improvement for the new POGIL-based lab course</b>	<p>The main objective of this lab course is to guide students to select a plastic material for a given design application through POGIL lab activities. An emphasis will be placed on sustainable materials selection for engineering design. The followings are the key components to design the POGIL lab activities:</p> <ol style="list-style-type: none"> <li>1. New POGIL activities are to be effective for students in learning and meeting the learning objectives.</li> <li>2. Students learn how to measure principal characteristics of polymers and polymer-composites in engineering design according to the testing standards.</li> <li>3. The laboratories’ practices encourage reducing the environmental impact of materials by the use of sustainable materials.</li> <li>4. Materials selection with an emphasis on sustainability and carbon footprint is to be emphasized.</li> <li>5. Student teams develop and present a marketing campaign on an assigned “green material” with the audience being a product manufacturer interested in becoming more sustainable.</li> <li>6. A team project where students are given a specific design requirement and asked to minimize the environmental impact for the application.</li> </ol>
<b>Measurable Outcomes</b>	<ol style="list-style-type: none"> <li>1. Students are able to be familiar with laboratory techniques in the testing and characterization of polymer materials for green plastics manufacturing technology.</li> <li>2. Students are able to characterize the properties of polymers and polymeric composites.</li> <li>3. Students are able to identify and select green materials for design.</li> <li>4. Students are able to analyze the lab experimental results and write laboratory reports following ASTM testing and ISO methods.</li> <li>5. Students are able to organize ideas in a logical way for team presentation and work within team environment.</li> </ol>

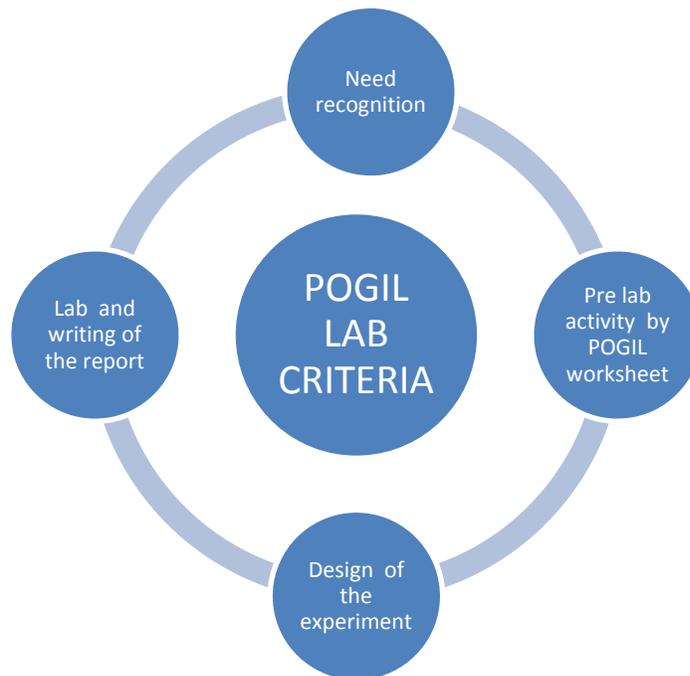
## **DESIGN AND DEVELOPMENT OF THE POGIL-BASED LAB**

The laboratory course, “Materials in Engineering Design Lab,” studies plastics testing principles of the American Society for Testing Materials (ASTM) and the ISO standards

testing methods; various types of polymers, including green polymers, and composites are evaluated and characterized for polymers selection and product design. Also, on the basis of the ASTM and ISO standards, the emphasis is placed on analyzing experimental results and preparing professional-quality laboratory reports for green plastics manufacturing technology (GPMT). This lab course is a core-required course that provides fundamentals of the polymers testing to the upper level of students (i.e., 3<sup>rd</sup> or 4<sup>th</sup> year status) in manufacturing and mechanical engineering technology programs at the Rochester Institute of Technology (RIT). Also, the course emphasizes the skills and knowledge needed in engineering tasks, such as teamwork and problem solving, for manufacturing products. The course syllabus provides the details of the course contents, structure, and delivery.

POGIL (Process-Oriented Guided Inquiry Learning) is the pedagogic strategy that develops the laboratory course structure. We developed the contents and practices of a lab-course in which the instructional design is to be utilized by cognitive development and a team learning environment. In addition, we implemented desirable criteria for the POGIL experiments in order to develop the instructional modules and POGIL lab-activities for GPMT.<sup>15</sup> The three desirable criteria for the POGIL experiments are:

1. Promotion of active decision making.
2. Encouraging students to develop questions for further research.
3. Allowing student input in design of experiments.



**Figure 1: Instruction model for GPMT lab**

Figure 1 shows the instructional model to develop the lab-practice modules; the POGIL lab-activity in each module contains the context of the POGIL experiments. Students work together in small groups at the laboratory; each group begins lab work recognizing the need of a material for a specific product; students work with a POGIL activity-worksheet in which

the goals and scope of ASTM testing, information, or data and learning objectives are presented in the worksheet; the problems in the POGIL worksheet are to guide students toward the design of the lab experiment and formulation of their own conclusions. The lab-instructor only serves as a facilitator, working with student groups if they need help during the lab. Students are encouraged to discuss and explain observed differences between the experimental and published values for the need recognition of the material tested and, thus, they can examine the validity of theoretical concepts as well as uncertainties resulted from a laboratory process. Students were finally required to write a paper on the laboratory exercise, which is graded against a defined rubric that assesses the lab-work on the activities, including standard test and theoretical approach, experimental process, data analysis, and discussion of the lab-results.

### ASSESSMENT AND EVALUATION OF THE POGIL-LABS

We analyzed one session of the POGIL lab in the fall of 2011-12 and three sessions in the spring of 2012-13, respectively; the total number of students in the four sessions was 49. Formative and summative surveys were performed to evaluate class activities, such as the POGIL approach, Green Plastics Manufacturing Technology (GPMT) practices, and Learning Objectives (LO), for the assessment and evaluation of the project; the pre-survey related to the students' understanding of green plastics (i.e. GPMT practices) was administered in the first week of class, and the post-survey was given at the end of the class for summative evaluation. In the formative evaluation of the POGIL activity, the survey also was given once every two weeks during the session.

The purpose of the student survey was to investigate how students felt about their experiences after completion of the lab classwork. The total of four POGIL surveys in each lab session asked students to give anonymous responses in order to monitor change in their learning experiences for the POGIL laboratory activity over the 10 weeks. The results of the survey were summarized to understand some implications of the POGIL format in the POGIL lab. The survey questions are listed in Table 2. Therefore, the findings and results of the surveys helped evaluate and improve the instructional model and learning modules of the POGIL laboratory courses in Green Plastics Manufacturing Technology (GPMT).

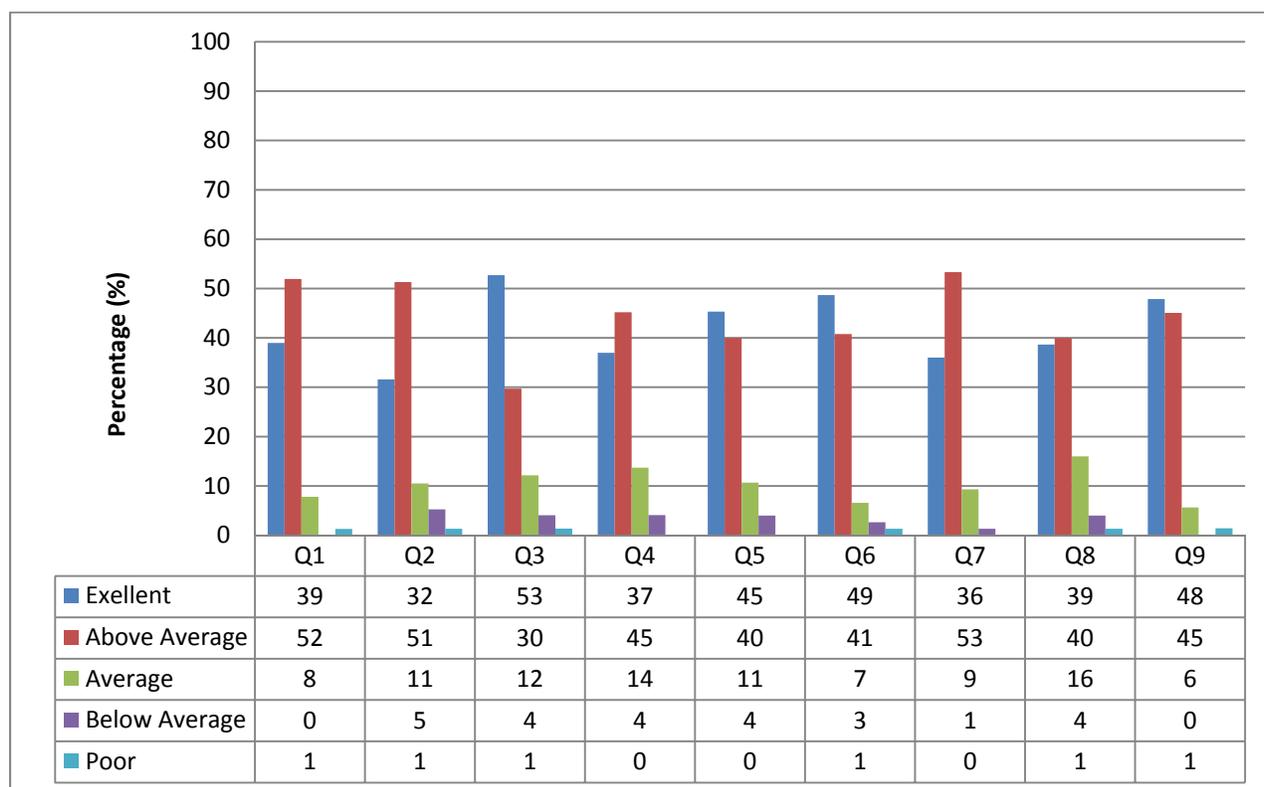
**Table 2: Questionnaires for the assessment and evaluation of the GPMT Laboratory Practices**

<b>Questionnaire</b>
Q1: The class and lab activities help me understand the background, learning goals, and fundamentals to study the subjects and complete the lab work.
Q2: The background information, concept questions and problems, and design problems of the class activity are clear and understandable.
Q3: Every group member was prepared well for the activities and she/he was willing to work together to complete the lab assignments in a timeline.
Q4: The class activities, lab modules, and assignments designed by Process Oriented Guided Inquiry Learning (POGIL) are effective to study the subjects and to do the

experimental work.
Q5: I was able to see the demonstration of lab experiment and it helped me understand the point of the lab work.
Q6: The lab experiments actually helped me learn certain concepts better and develop critical thinking and problem skills.
Q7: Terms and/or concepts that I was unsure of became clearer with the lab activities.
Q8: Each group member was knowledgeable and skillful in the subjects.
Q9: The instructor was helpful to guide the activities and to develop skills (learning, thinking, and problem solving) during the class and lab.

The results of the survey were summarized to understand some implications of the POGIL laboratory practices. Figure 2 summarizes the accumulative responses of the survey-results in the GPMT laboratory education. The results of the accumulative responses in the surveys indicated strong/ positive perceptions and attitudes for the new instructional model and re-designed curriculum modules in the POGIL lab.

**Figure 2: Accumulative Responses of the Surveys in GPMT Labs**



## **Learning Effectiveness by the POGIL Laboratory Techniques (Q1, Q2, and Q7)**

The survey questions of Q1, Q2, and Q7 were to assess and evaluate the effectiveness of the POGIL Laboratory techniques using the guided inquiry lab materials. The survey results indicated positive responses to the POGIL lab environment implemented by the new approaches, although there were disagreements. For example, strong agreement responses (i.e., excellent) in Questionnaires 1, 2, and 7 were 39% and 32%, and 36%, respectively. Agreement responses (i.e., above average) were 52%, 51%, and 53%, respectively. Neutral responses (i.e., average) to the questions were 8%, 11%, and 9%, respectively, in the accumulative responses of the surveys.

However, strong disagreement responses (i.e., poor) were negligible in most questions, and disagreement responses (i.e., below average) were ranged between 0% and 5%, respectively. Active learning is generally defined as any instructional method that engages students in the learning process.<sup>11-12</sup> These survey-results reflected the effectiveness of learning modules in various lab activities.<sup>15-17</sup>

Some negative responses were to be considered in Questionnaire 2 which measured a level of the comprehension of the learning modules for the POGIL lab activities. Such negative responses showed that students, who had limited experiences in POGIL learning environments, might find a difficulty to adapt a new learning strategy to study the subjects by means of the active learning modules through the POGIL activities. The POGIL-based lab does not present lectures to explain the concepts and to present analogies to provide answers for the laboratory exercises. Since the carefully-designed lab exercises use pedagogy in guided inquiry learning in which the learning module demonstrates step-by-step procedures for how to solve various problems during the lab experiment. The majority of the students felt they already had a strong interest in learning course materials by the POGIL-based learning modules, according to the survey results.

## **Adoption of new POGIL laboratory Practices (Q4, Q5, and Q6)**

The new POGIL instructional model (Figure 1) and laboratory practices require the students to work through a meaningful learning environment by the POGIL approaches. The meaningful environment is one in which students can learn effectively and develop crucial skills in the POGIL laboratory exercises; the skills are presented as outcomes in Table 1.

Strong/positive agreements (i.e., both “excellent” and “above average” in the survey) for Questions 4-6 were shown in Figure 2. For example, strong agreement responses (i.e., “excellent”) in Questionnaires 4, 5, and 6 were 37%, 45%, and 49%, respectively. The agreement responses (i.e., “above average”) were 45%, 40%, and 41%, respectively. Neutral responses (i.e., “average”) to the questions were 14%, 11%, and 7%, respectively. These strong/positive responses suggested that students could effectively learn a conceptual understanding of the course subjects through these new instructional model and lab modules as well as obtain some benefits (i.e., lab-preparation and -technique skills) offered through traditional learning.

Although some students were skeptical to an active learning format, the new POGIL-based laboratory led students to actively learn by the guided learning inquiry. The results suggested that the design of learning module should focus on the effectiveness of the activity rather than

the presentation of the format; this is the essence of a student-centered classroom/laboratory by the POGIL approaches.

### **Team Learning and Instructor Facilitation (Q3, Q8, and Q9)**

Questions 3, 8, and 9 represent collaborative learning, which provides students one of the key elements to appreciating the active learning environment in the POGIL laboratory. From the results of the surveys, the strong agreement responses (i.e., excellent) were 53%, 39%, and 48%, respectively. The agreement responses (i.e., above average) were 30%, 40%, and 45%, respectively. Students strongly agreed upon the importance of preparedness and helpfulness of their team members during the activities. We observed similar responses in other POGIL-based courses.<sup>6-9</sup> Significantly, in Question 9, students recognized the critical role the instructor played in various learning activities. This reflects that active instructor presence still played an important role in either the traditional or active learning model.<sup>15,17</sup> Even though the learning experience could be improved by students constructing their knowledge and skills through working together, some students were not willing to share their knowledge and skills with their team members in the activities.<sup>8</sup>

In the POGIL environments, not only did students teach one another, but they also teach the instructor by revealing their understanding of the subjects. This new paradigm is a common finding that knowledge results only through active participation in its construction by active learning environments.<sup>10-17</sup> The new POGIL-based lab was to promote students to actively be engaged in learning and, thus, the guided learning inquiry could result in the positive attitudes to active learning.<sup>15-17</sup>

### **CONCLUSIONS**

- We developed the POGIL lab instruction model and laboratory practices on how polymeric materials are to be evaluated and characterization for green design.
- The POGIL-based lab emphasizes the skills and knowledge needed in engineering tasks, such as teamwork and problem solving, for manufacturing products.
- We assessed and evaluated the effectiveness of the POGIL Laboratory techniques using the guided inquiry lab materials. The survey results indicated positive responses to the POGIL lab environment implemented by the new approaches, although there were disagreements.
- The strong responses in agreement suggested that students could effectively learn a conceptual understanding of the course subjects through the new lab modules as well as obtain some of the benefits (such as lab preparation and design for improving design skills) offered through traditional learning.
- Students strongly agreed upon the importance of preparedness and helpfulness of their team members during the activities. We observed similar responses in other POGIL-based courses. Students recognized the critical role the instructor played in various learning activities.

## ACKNOWLEDGEMENT

The National Science Foundation (Awards: DUE-1044794 and IIP-1261136) supports this GPMT project.

## Bibliography

1. American Council on Education. Higher Education Goes Green: Solutions for Our Future Highlights Campus Sustainability Efforts, <http://www.acenet.edu/AM/Template.cfm?Section=Home&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=26428>
2. Green California Summit and Exposition. Green California Summit 2009: the Biggest Yet!" <http://www.green-technology.org/gcsummit/>
3. The White House, Energy and Environment, <http://www.whitehouse.gov/issues/energy-and-environment/>
4. Mohanty, A. K, Misra, M., and Drazal, L. T. Sustainable Bio-composites from Renewable Resources: Opportunities and Challenges in the Green Materials World, *J. of Polymers and the Environment*, 10 (2002), 19-26.
5. Biodegradable plastic, [http://en.wikipedia.org/wiki/Biodegradable\\_plastic](http://en.wikipedia.org/wiki/Biodegradable_plastic)
6. Spencer Kim, "Transforming Undergraduate Curriculum for Green Plastics Manufacturing Technology (GPMT)," 2013 Annual Conference for ASEE, 2013 ASEE Annual Conference, June 23-26, Atlanta, GA.
7. Spencer Kim, "Transforming Curriculum for Workforce Development in "Green Plastics Manufacturing Technology" (GPMT)," 2013 CCLI/TUES Conference, Renaissance Hotel, Washington DC, Washington, District of Columbia, Jan. 21-22, 2013.
8. Spencer Kim, "Materials Education for Green Plastics Manufacturing Technology (GPMT)," 2012 Annual Conference for ASEE, San Antonio, Texas, June 10-13, 2012.
9. Spencer Kim and Betsy Dell, "Transforming Materials Education in Mechanical Engineering Technology, 2012 Faculty Institute on Teaching and Learning, RIT, May 30-31, 2012.
10. Mohamed, A., Effects of active learning variants on student performance and learning perception, *International J. for the Scholarship of Teaching and Learning*, Vol. 2, No. 2, July 2008.
11. Prince M., Does active learning work? A review of the research, *J of Eng. Edu.*, 1-9, July 2004.
12. Reigeluth M. Charles. *Instructional-design Theories and Models: An Overview of their Current Status*, Published by Lawrence Erlbaum Associates, 1983.
13. Hmelo-Silver, C., Ducan, R., and Chinn, C., Scaffolding and achievement in problem based and inquiry learning: a response to Kirschner, Sweller and Clark (2006), *Educational Psychologist*, 4292, 99-107, 2007.
14. Eberlein, T., Kampmeier, J., Minderhout, V., Moog, R., Platt, T., Varma-Nelson, P., and White, H., Pedagogies of engagement in science, *Biochemistry and molecular biology education*, 36 (4), 262-273, 2008.
15. POGIL, <http://www.pogil.org/>
16. Schroeder, J., Greenbowe, T., Implementing POGIL in the lecture and the science writing heuristic in the library-student perceptions and performance in undergraduate organic chemistry, *Chem. Educ. Res. Prat.*, 9, 149-158, 2008.
17. Sriram Sundararajan, LeAnn E. Faidley, Terrence R. Meyer, Developing inquiry-based laboratory exercises for a mechanical engineering curriculum, American Society for Engineering Education, San Antonio, Texas, June 10-13, 2012.
18. Spencer Kim, "Development of a Laboratory Module in Hybrid Biodegradable Thermoplastic Cornstarch Materials," 2011 Annual Conference for ASEE, June 26-29, BC, CANADA.