Transforming Curriculum for Workforce Development in Green Plastics Manufacturing Technology (GPMT) for STEM: Lesson Learned

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Introduction

Manufacturing is integrally tied to advancements in materials science and engineering. "Green Plastics Manufacturing Technology" (GPMT) is an emerging discipline that encompasses a range of activities in science and technology, from the research and development of non-toxic and eco-friendly materials to the reduction of waste and pollution through changing patterns of production and consumption.[1,2] Most subjects in the materials and manufacturing curriculum in engineering and technology cover the fundamentals of current engineering materials (i.e. metals, ceramics, petroleum based polymers and plastics, and composites) and traditional manufacturing processes; however, few prepare students to work with a broad range of new/future materials, particularly green-sustainable materials (such as, green nano-materials, biodegradable polymers, and ecofriendly-hybrid materials) along with advanced manufacturing. Furthermore, the traditional approach to teaching materials and manufacturing technology does not appeal to students studying new manufacturing processes and systems for a new discipline in Green Plastics Manufacturing Technology (GPMT).[1-4]

The primary goal of the NSF project (DUE-1044794) was to transform the exiting materials and manufacturing curriculum to keep pace with advanced green technologies in the manufacturing and mechanical engineering technology programs (MMET) at Rochester Institute of Technology (RIT). We developed new educational approach and undergraduate teaching modules to promote STEM practice for Green Plastics Manufacturing Technology (GPMT) within foundational courses in materials and manufacturing education for the MMET programs.

The GPMT approaches, which were based on the findings and results in the evidence-based pedagogy, were applied to develop a new instructional model and to transform traditional style in teaching to more student-centered, interactive, team-learning based method for the engineering technology discipline. Therefore, the outcomes of this NSF project brought innovation and changes, not only in terms of creating an effective instructional model for STEM education, but also by encouraging students, as future workforces, to participate in various undergraduate research projects as they prepared for careers in the field of green manufacturing technology.[1-5]

Instructional Approach

Manufacturing has played a critical role in the technological evolution of our society, from structural steels to electronics and robotics technology. The GPMT, as a multidisciplinary field in plastics manufacturing technology, deals with product design, prototyping and modeling, production and process optimization, quality control and failure analysis, materials testing and characterization, process automation and robotics, and environment technology.[1-5]

This NSF project utilizes Science, Technology Society & Environment (STSE) instructional strategies. The STSE strategies link topics in the science and technology fields to their human, social and environmental contexts by including a variety of perspectives on scientific disciplines; historical, philosophical, cultural, sociological, political and ethical. The STSE approach cuts across disciplines as part of a broad effort to understand, analyze, and consider the consequences of social, scientific, technological issues in science and technology.[6-10]

Waste management, preservation of natural resources, health issues related to production, government intervention in the banning of plastic materials or additives, and economic factors related to the adoption of green plastics are all areas that are deeply intertwined with society and a humanistic perspective to science and technology. The topics of green polymers and plastics manufacturing for undergraduates are especially suited by the STSE strategies. Figure 1 shows a model to integrate STSE and environmental and society factors for the development of innovative and sustainable technology for the green plastics manufacturing technology.[1-5]

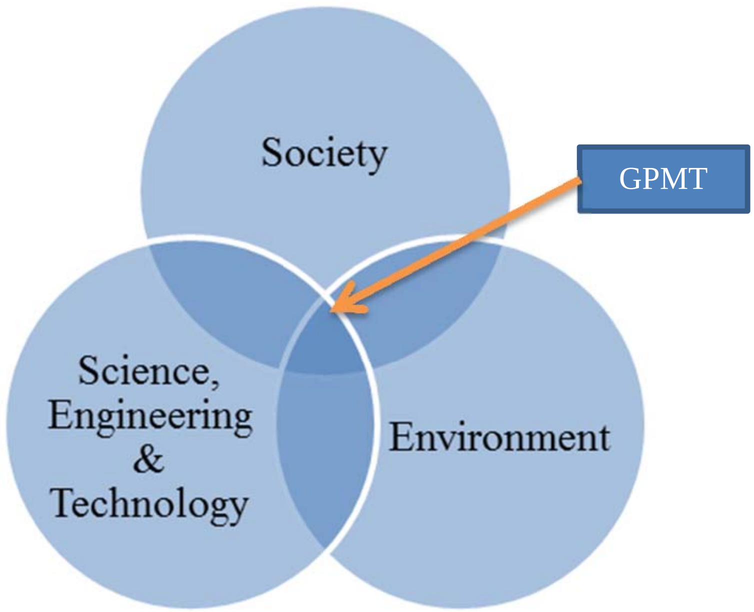

Figure 1: GPMT Model for innovative and sustainable green technology development by integrating science and technology, environment, and society factors

Curriculum Design, Development, and Improvement

We implemented the STSE strategies to design an instructional model for GPMT education (Figure 1). We also applied the Process-Oriented Guided Inquiry-Learning (POGIL) approaches for the development of leaning modules; POGIL is an evidence-based, active-learning pedagogy where students work for learning in teams to acquire knowledge and develop understanding topical subjects through guided inquiry.[11-15] With POGIL, students could acquire key processing skills as they learned the discipline contents throughout the activities.[1-5, 11-15]

Some of the project outcomes indicated that the design and development of the learning modules were critical to induce students' willingness to apply new instructional strategies for the classroom or lab activities.[1-5] In addition, the evidences showed that team-based projects in the laboratory course could effectively exposure students to develop knowledge and skills in the characterization of green materials for engineering design.[4-5]

For example, in a team-based research project, student teams were assigned to study various types of green plastics and asked to develop sustainable products for commercial applications. During the project, the students studied the properties, biodegradability, and process-ability of the selected green material according to the design limits, and considered the societal impacts of the product on toxicity, waste management, and the environment (i.e. carbon footprint and water usage in production).[4-5] We also introduced the use of a software tool (i.e. materials and process selection software) to estimate the carbon footprint, energy usage, and durability of green plastics in laboratory modules. Even though many new inventions and advancements in materials science and manufacturing technology provide useful tools to adapt alternatives, (such as nano materials, fuel cells, solar technology, green materials, etc.), it's critical to infuse humanistic inquiry into the instructional model for undergraduate education.[1-5, 16]

In the GPMT laboratory, we set up a small-scale green plastics production line with prototyping, extrusion, and injection molding machines. Thus, the low-division students were able to experiment with green materials for the lab activities, and the upper division students could conduct applied research projects in green plastics manufacturing through co-op.[17-20]

Assessment, Evaluation, and System Approach

The traditional-transmission learning format, in which the degree of a student's success depends only on the performance of quizzes, tests and projects in class, does not truly reflect the effectiveness on learning and skills application.[1-5, 11-15] We proposed a system approach to draw on the analysis and evaluation of student's learning outcomes and thus, were able to design a curriculum model to improve an instructional structure and to reformulate the instructional strategies for the effectiveness in learning for the GPMT education. Figure 2 illustrates the system approach developed for the curriculum design model of GPMT education.[1-3] We adopted more collaborative approaches for this NSF project to break away from traditional norms in education, while assessing students' abilities in various formative and summative cases; many aspects in learning effectiveness are interconnected by the three key components (instruction improvement, learning effectiveness and student performance).[1-5]

We developed the contents, leaning modules, and laboratory practices for the courses in which the instructional design was utilized by cognitive development and a team learning environment; undergraduate students learn the basic principles in class and performed in hands-on practices in laboratory by POGIL approaches. Also, we encouraged students to participate in undergraduate research projects which resulted in the improvement of research skills to potential employers in manufacturing or for advanced study in graduate programs.[17-20] As a result of the assessment and evaluation, we were able to identify strengths and weaknesses to reform the traditional-transmission format for students' learning effectiveness in the formative and summative purposes.

The formative and summative evaluations helped us optimize the results to develop and improve the course contents in Green Plastics Manufacturing Technology. Using the system approach (Figure 2), we could continue to reformulate the instructional strategies and produce new learning modules so that students were less concerned with finding the best means to an end, but with reconciling and deciding among the ends or goals themselves for societal perspectives. For example, students could evaluate relevant theories and empirical results by considering how a particular process or material measures up in terms of societal and/or environmental considerations.[1-5] Based on the evidences and findings in the assessments and evaluations of the project, the newly-developed system approach was helpful in adopting an evidence-based instructional method, which has a more student-centered learning format.

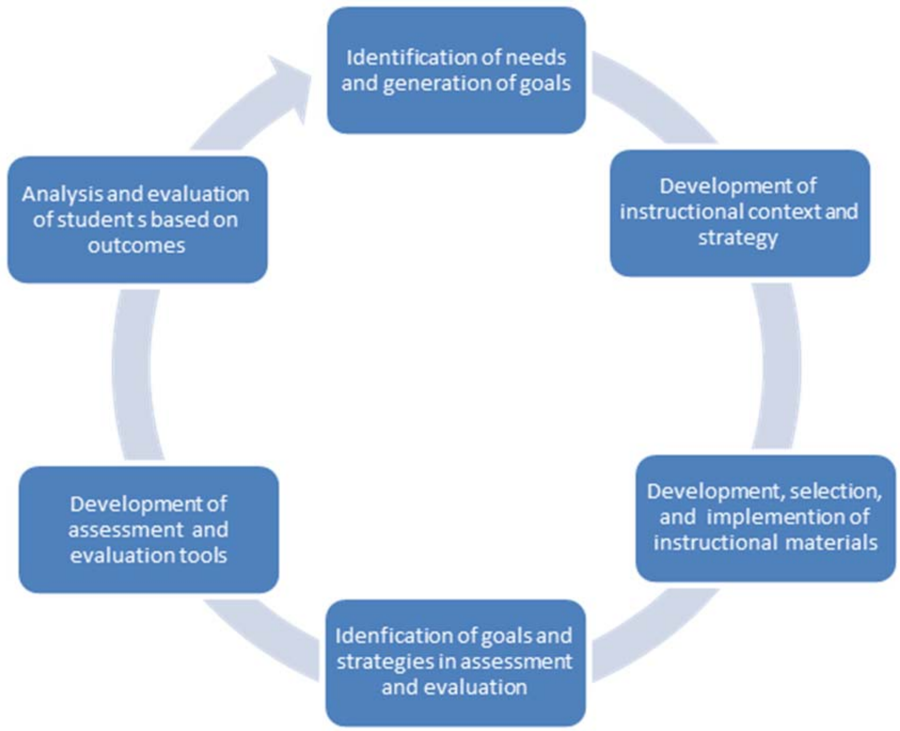

Figure 2: System approach in the development and improvement of curriculum for GPMT

Evidence-based Pedagogy in GPMT Education

The key goal of the project was to develop an instruction model and learning modules to transform the materials and manufacturing curriculum, so that students are well prepared to pursuit professional careers in green manufacturing technology. We enhanced five current core courses (materials technology, mechanical engineering technology lab II, plastics processing technology, solid modeling and design, and robotics in manufacturing) and established an intensive undergraduate research program for co-op students and students taking independent study in the manufacturing and mechanical engineering technology programs. These improved courses deal with 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 instructional strategies.[1-5, 16]

We implemented the analytical results for the improvement of the activities and work of the project, while closely worked with the evaluator. The evaluator obtained and analyzed the data from the PI and Co-PIs regarding individual work matrix sheets, formative and summative evaluation of classroom events and exams, viewed MyCourses (i.e. courseware), course development web-site, and visited classes in the sessions. The outcomes of the project were focused on the learning effectiveness achieved by the students who participated in various activities in the programs, the contribution of the project to STEM education and the recruitment of women and minority students. The results of the evaluations indicated that the POGIL approach had improved students' critical thinking and problem solving skills significantly and the re-designed of the six courses contributed to students' learning of the GPMT concepts. The outreach program of the project was very effective in stimulating participants' interests in the fields of engineering technology as majors, attending RIT and their understanding of green materials in GPMT practices.

The evidence based techniques were effective to measure the success of each of the goals and objectives presented in the proposal, in addition to a professional reviewer that also oversaw and measured the quality of the project outcomes. We are sure that evidence-based instructional practices met the goals and objectives of the project and continue to offer the reformed courses in the discipline. The outcomes of the project from the analysis and evaluation were documented and disseminated according to strategies shown in Figures 1 and 2. Since the evidences, finding and outcomes resulted from the project had been presented and disseminated in the conferences and publications, we present examples of the evidences and findings, as case studies, in the following sections.[1-5, 16-20]

Example in POGIL-based Learning Format

"Materials Technology" is a core-required course that provides fundamentals in materials science and technology to the upper level of students (i.e., 4th 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.

During the project period, we continued to implement a learner-centered curriculum model and to improve course contents for the materials technology course by various POGIL activities; most traditional classroom lectures were replaced by learner-centered learning modules—primarily guided inquiry learning activities; online lectures, class discussions, and online quizzes were posted for student to prepare for the course. Students were encouraged to open their books and review the online PowerPoint materials before engaging in the POGIL activity. In the classroom, students collaborated with their team members in order to complete an assigned class activity in a timely manner, and they took an online quiz to measure the confidence level in learning. The instructor monitored the POGIL activity and provided details whenever students asked in the class-activity sheets. The POGIL class activities were developed and used to mainly cover topics such as:

- Interrelation of properties, structure, processing, and performance for materials with emphasis placed on materials and process selection for design application.
- Special considerations given to the impacts of materials on the environment, economics, and society in selection and design.
- Selection and design of materials and manufacturing processes with an emphasis on sustainability and carbon footprint.

- Team project to understand specific design requirements and to minimize environmental impact for the application while achieving cost effectiveness.

The formative and summative surveys were performed to evaluate class activities, such as 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 especially for the summative evaluation. In the formative evaluation of the POGIL activity, the survey was also given once every two weeks during the last class of each session. The surveys helped evaluate and improve the instructional model and learning modules of materials and manufacturing courses in Green Plastics Manufacturing Technology (GPMT).[1-3]

The results of the accumulative responses in the surveys revealed strong and/or positive perceptions and attitudes for the new instructional model and re-designed curriculum modules in materials technology for the GPMT education among students. The results suggest that students could effectively learn all three categories of the GPMT practices for the course subjects with the new methods by POGIL approaches. The POGIL classroom activities encouraged students to actively be engaged in learning (i.e., the guided learning inquiry). This could result in the positive attitudes in practicing the GPMT, as well as prepare the future workforces in the field of GPMT.[1-5, 16-20]

GPMT Recruitment and Retention Efforts

One of the objectives of the GPMT project was to recruit minorities and women to STEM education programs. Sixteen different outreach programs were held during the project. These programs had three main demographic focus areas: 1) high school technology teachers through a partnership with Project Lead the Way, 2) minority students through relationships developed with local low income school districts and 3) activities coordinated with RIT's Women in Technology program (WIT).

At most outreach events, pre and post surveys were given to the students to determine their interest in pursuing engineering technology as a major in college, attending RIT and their understanding of plastics as green materials. In 2012, it a decision was made to simply provide a post survey. In previous years, we saw students' attitudes to pursuing a career in engineering and/or interest in an engineering technology major decrease after their participation. We believe when the participants completed the "Pre-survey", they did not have a clear understanding of what engineering or engineering technology was. After learning about these fields, they were able to make a more educated choice on the survey. One assessment of the effectiveness of recruitment programs and pedagogical changes to retain underrepresented groups was to track the enrollment of women students and minority (specifically African American, Latin American and Native American or AALANA) in the Manufacturing and Mechanical Engineering Department (MMET).

The project hosted nine outreach events during its lifespan. These events targeted underrepresented groups in STEM careers, women and minorities. The total number of participants is 561 comprising of 429 students plus 132 school teachers/counselors. Nearly 33% of the outreach participants were ethnic minority students and 71%were female. The total of 561participants is above the expected number of 500 that the project had intended to reach. From the time the proposal was written to today, the percentage of women in the MMET department has increased from 7.43 to 8.20 % and AALANA students has increased from 13.62 to 18.24 %.

The outreach program was very effective in stimulating participants' interest in engineering technology as a major, attending RIT and their understanding of plastics as green materials.

Lesson Learned from the Project Outcomes and Experiences

We present some of major findings and evidences resulted from the analysis, evaluation and experience in the NSF project as follows:

- Implementing the GPMT curriculum model and using key strategies from new instructional model could develop students' skills and knowledge that are far more memorable and transferrable than traditional delivery in STEM education.
- The cognitive development and team learning environment could be utilized by guided inquiry strategies, as an active learning format.
- The overall responses across the assessments and evaluations for the project objectives were most favorable rating indicating that students generally agreed with the positive statements about the POGIL-based activities in the reformed courses. POGIL approaches could help us develop course materials and laboratory practices emphasizing skills and knowledge needed for engineering tasks, such as teamwork and problem solving in manufacturing.
- Undergraduate research opportunities through the activities and hands-on laboratory experiences through activities and participations could promote students to consider careers in the subjected fields or to enter graduate schools for advanced studies.
- The GPMT practice was useful to encourage minority, underrepresented group of students, and women to promote STEM and to increase the enrolment in engineering technology programs.

Conclusions

We developed a new instructional model to introduce green plastics manufacturing technology (GPMT) into the existing undergraduate courses and promote undergraduate research activities in order to produce the future workforces in GPMT. The new instructional model could define a curriculum design process to optimize the goals for the STEM education. In addition, the transformation of the materials and manufacturing curriculum utilized the instructional approaches from Science, Technology Society & Environment (STSE), offering topics from engineering materials to the social and environmental context in manufacturing. To promote active learning, the Process-Oriented Guided Inquiry-Learning (POGIL) approaches were applied to develop new instructional modules. Also, by incorporating green plastics manufacturing technology and focusing on its social benefits, we attracted more women and minorities to the programs. We could utilize the existing facility to reach out to high school students to stimulate their interests in eco-friendly technology and its environmental impacts. With the results of the NSF project, students could practice their skills and deepen their understanding of shared social responsibility through working cooperative education jobs related to green plastics manufacturing technology. The outreach program was very effective in stimulating participants' interest in engineering technology as a major, attending RIT and their understanding of plastics as green materials.

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