AC 2012-5073: MATERIALS EDUCATION FOR GREEN PLASTICS MANUFACTURING TECHNOLOGY (GPMT)

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Materials Education for Green Plastics Manufacturing Technology (GPMT)

Introduction

A recent campaign, "Green Solutions for the Future," identified the creation of green jobs, infrastructure projects, renewable energy research and development, and education as major issues and challenges facing the nation.[1,2,3] From using eco-friendly products to driving electric cars, there are many opportunities for consumers to lower their carbon footprints and energy consumption. 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.[4] Clearly, increasing availability of renewable, recyclable, sustainable, and biodegradable products will make a significant contribution to the environment.

Sustainability, industrial ecology, and green chemistry are guiding the development of the next generation of materials, products, and processes. Natural/bio-based materials are emerging as a viable alternative to petroleum based plastics especially in automobile and packaging applications. Furthermore, the combination of inorganic/organic fillers with biodegradable plastics can produce eco-friendly hybrid materials that could be competitive with synthetic plastic composites for various applications.[5,6]

Plastics manufacturing technology is a multidisciplinary field that deals with product design, prototyping and modeling, production and process design, materials testing and characterization, process automation and robotics, and quality control. "Green Plastics Manufacturing Technology" (GPMT) is an emerging discipline that encompasses a range of activities, 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. Even though there is an increasing need for engineers and technologists to work in this field, we know of no current *undergraduate* curriculum for engineering technology in the United States that educates students to step into careers in the new Green Plastics Manufacturing Technology field.

One of the most important subjects in engineering and technology programs is manufacturing. Manufacturing involves a complex system of materials, machines and people. Most subjects of the curriculum in manufacturing 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/future materials, particularly green materials (such as, green nano-materials, biodegradable polymers, and ecofriendly-hybrid materials) in advanced manufacturing technology. The primary goal of the study was to transform the exiting materials curriculum to keep pace with the new green technologies in the manufacturing and mechanical engineering technology programs at Rochester Institute of Technology (RIT). We attempted develop and pilot test an educational approach and undergraduate teaching modules for Green Plastics Manufacturing Technology within foundational courses in the materials and manufacturing education.

Instructional Model

The optimal methods of instruction are to bring some desired outcomes in knowledge and skills in green materials and manufacturing technology for undergraduate students in the engineering technology programs. Therefore, an instructional model, as a systematic process, is developed so that all the elements of the system are inter-related to continually monitor the outcomes and modify the instructional model as needed until it reaches the teaching goals for STEM education; that is, the elements (i.e., instructor, students, course materials, and learning environment) are tightly related to work together toward defined teaching goals and objectives.[7]

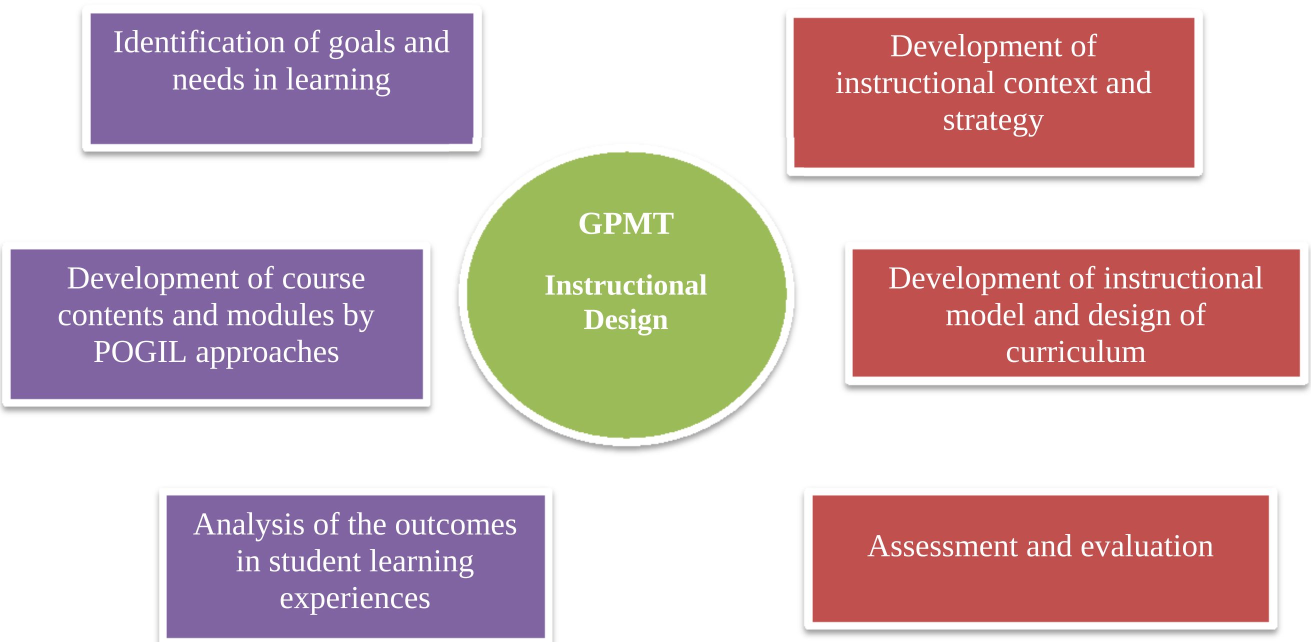


Figure 1: System approach in instructional design

Figure 1 illustrates a system approach to developing an instructional model in green plastics manufacturing education. This model we developed draws on analysis of student's learning outcomes to redesign an instructional format and to reformulate the instructional strategies for the effectiveness of teaching. The formative evaluations help us optimize the outcomes to teach "Green Plastics Manufacturing Technology."

Even though many new inventions and advancements in green materials science and manufacturing technology provide useful tools to adapt alternatives, (such as nano materials, fuel cells, solar technology, green materials, etc.), the instructional model should infuse humanistic inquiry into the course materials; students are less concerned with finding the best means to an end, but with reconciling and deciding among the ends or goals themselves for humanistic perspectives. For example, students will evaluate relevant theories and empirical results by considering how a particular green material or manufacturing process measures up in terms of cultural, ethical, or societal considerations.

Process-Oriented Guided Inquiry-Learning (POGIL) for Engineering Technology Education

All learning involves knowledge construction in one form or another; it is therefore a constructivist process.[8] With increasing interest in innovative approaches such as student-centered, active learning, and peer-led team learning, the POGIL, project based learning (PBL) and other educational approaches have received attention within the educational communities. Particular approaches may be suitable to the specific characteristics of the student and audience, facilities, instructional goals, personal preferences, and educational resources.[8,9]

Process-Oriented-Guided-Inquiry-Learning (POGIL) is an educational approach in which effective student-centered instruction is the norm.[9] POGIL is designed to replace traditional lecture-only methods by encouraging students to discuss course materials, rather than just listen to the instructor.[9] The innovative POGIL approach is a nationally tested and proven pedagogical strategy that incorporates recent educational research on how students learn from kindergarten through post-secondary education. The POGIL approach relies on inquiry based, student-centered classrooms and laboratories that enhance learning skills while insuring content mastery.[8,9,10] With POGIL, students can acquire key processing skills as they learn the discipline content. Our new instructional strategies are to improve or develop the materials and manufacturing curriculum utilizing by “Process-Oriented Guided Inquiry-Learning” (POGIL). With POGIL, students can acquire key processing skills as they learn the discipline content.

Literature in the field of student learning indicates that the POGIL approach has been effectively used in disciplines such as mathematics, biology, and chemistry for post-secondary education.[9] However, we have found no reports proving the efficacy of this strategy in engineering technology, which is a highly applied discipline.

Green Materials and Manufacturing Curriculum

Manufacturing technology is integrally tied to advancements in materials technology. Materials technology has played a critical role in the technological evolution of our society, from structural steels to optoelectronics and robotics technology. The newly-designed materials course deals 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 proposed instructional strategies.

In engineering design, the performance of products is related to technical advances in materials. For example, polymers are the choice of materials in various applications because they provide low cost and high strength-weight ratio. In the last several decades, many discoveries have led to polymers with the high strength, conductivity or optical properties of other materials, often combined with unique processing and nanofabrication capabilities. Because of advances in technology and the growing demand for environmentally friendly products, manufacturing technology has become an increasingly important component of today’s STEM education. Engineering and technology educators must impart competencies so that students can apply their knowledge and skills in relation to current engineering materials, as well as preparing students to work with the green materials of the future in advanced manufacturing.

Materials Technology Curriculum Design

The materials course considers the interrelation of properties, structure, processing, and performance of materials for juniors (i.e., third or fourth year students) in manufacturing and mechanical engineering technology programs. Emphasis is placed on materials and process selection for green design application.

The primary approach of the curriculum design 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 following table (Table 1) summarizes the course design for the improvement of the materials curriculum according to the instructional model, curriculum design and strategies presented in the previous sections.

Also, the measurable outcomes of new curriculum model are developed to relate to some of the student outcomes in General Criterion 3 for the ABET; these ABET criteria are "a, b, d, e, f, g, h, i and j." The assessment tools and student outcomes are presented to improve the learning models in the proceeding sections.

Table 1: Materials Curriculum Design

	Description
Old course structure	The course considers the interrelation of properties, structure, processing, and performance for non-metallic materials. Emphasis is placed on materials and process selection for design.
Innovation and Improvement for the course	The course continues to consider the interrelation of properties, structure, processing, and performance for non-metallic materials, but emphasis is placed on materials and process selection for design application with special consideration of their impacts on the environment, economics, and society. The mechanisms of degradation of current and green materials are discussed, along with ways to minimize the effects of these mechanisms in green manufacturing. Students will learn how to reduce the environmental impact of materials on green manufacturing. Materials selection is emphasized in terms of the sustainability and carbon footprint.
Measurable Outcomes	1. Students will learn how to identify and quantify environmental impact of a material for a given design. 2. Students will be able to relate the structure-processing-property relationships of the current engineering materials and new green materials. 3. Student will select appropriate materials for a given application to minimize environmental impact. 4. Students will demonstrate the ability to synthesize from different subject areas in making sustainability informed materials selection including sound mechanical design and attention to - public policy, management and environmental considerations.

POGIL Activities and Learning Modules

"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 summer of 2011, we developed a learner-centered curriculum model for the materials technology course (Table 1). Within this model, "Materials Technology" course was re-designed in which approximately 50 to 60 % of classroom lectures were replaced by the learner-centered learning experiences—primarily POGIL activities. The rest of the sitting time was used for mini-lectures, online lectures, class discussions, online quizzes, tests, and other group activities.

Table 2 shows the course modules and contents which were divided up into five different sections in materials technology in terms of the study subjects. Students study each module in a two-week-period out of the ten-week session in quarter; each module employs active learning strategies using POGIL approaches. During the course, there was a term project assigned, as a group work, in green materials and design. PowerPoint lectures were posted to deliver the study materials and, thus, students were prepared for various POGIL activities in classroom.

Table 2: Modules and course contents

Module No.	Course Contents
Module 1	Introduction to materials: types of materials, materials, structure-property-processing relationships, and environment, and design and selection of materials for design.
	Applications and processing of metal alloys: ferrous alloys and nonferrous alloys
Module 2	Atomic structure and types of bonding in materials, short range order vs. long range order, amorphous and crystalline materials, allotropic or polymorphic transformations, 4) materials selection and design
	Mechanical properties, variability of materials property, design and safety factor in materials
Module 3	Polymers: classification of polymers, chain formations, thermal behavior, degree of polymerization, arrangement of polymer chains, controlling structure, properties of thermoplastics, thermoplastics and thermosets and elastomers, processing technology, and selection and design, and biodegradable polymers.
Module 4	Ceramic materials: crystalline and noncrystalline ceramics, processing and applications of ceramics, and advanced ceramics.

	Composites: types of composites, mechanical properties and design of composites, and processing and applications.
Module 5	GPMT (Green plastics manufacturing technology): economic, environmental, societal issues in green materials and processing technology
Group Project	Project presentation and evaluation

We utilized the POGIL philosophy to develop the class activity-sheets in materials technology; these activity-sheets were based upon pedagogical approaches in the instructor's guide developed by Professor David Hanson. The example of class activity-sheets ("Class Activity 8") is presented in Appendix.

Class time was provided for students to collaborate on the POGIL activity in a timely manner. Online quiz was assigned after the POGIL class activities were completed almost every week. In class, students worked cooperatively in the groups of 4-5 students on guided inquiry class-activity materials designed based on the POGIL. Students were encouraged to open their books and review the online PowerPoint materials before engaging in the POGIL activity. The instructor monitored the POGIL activity and provided details whenever students asked in the class-activity sheets. There were some parts in the lectures in that the instructor needed to cover thoroughly in the Monday classroom sessions (i.e., the first session of the week), and those were called "keepers." These keepers were presented in the Mondays (i.e., the first session of the week) and usually covered the introduction of new concepts or more difficult topics where student questions could be followed up and elaborated as necessary during the class activity. In the last class session of the week, students were asked to complete a survey for the assessment and evaluation of the course after the online quiz was finished.

Assessment and Evaluation

The purpose of the student survey was to investigate how students felt about their experiences after completion of the class works. In the fall of 2011, a total of 22 students were enrolled in the materials technology course and met the four sessions (a 50 min per session) a week; one session was spent for the online quiz and student survey. The total of eight surveys was anonymously asked to the students in order to monitor change in their learning experiences in class for the POGIL activity over the 10 weeks. The results of the survey were summarized to understand some implications of the POGIL format in materials technology. The survey questions are listed in Table 3.

Table 3: Survey Questionnaire

Number	Questions
Q1	Class activity helps me understand the background, goals and objectives to study materials technology.
Q2	The background information, questions, and problems of class activity are clear and understandable.

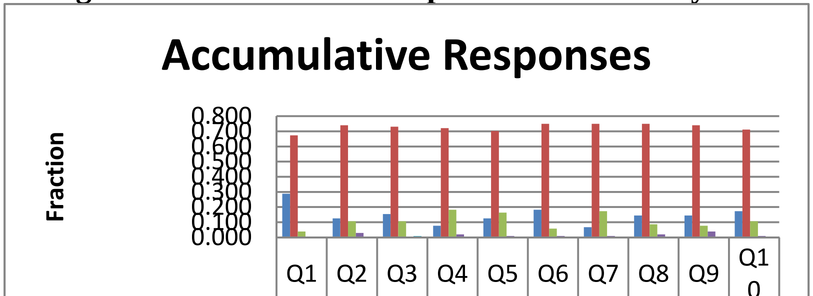
Q3	All course materials (in-class lectures, online lecture notes, activities, information, etc.) make me well prepare for the class.
Q4	The problems and questions in the class activity module are understandable and challenging.
Q5	Every team member was prepared well for the group activity and work.
Q6	Both class and group activity-modules help me learn more in the subjects of the course.
Q7	The activity modules designed by guided learning are somewhat effective to study the subjects.
Q8	Instructor was helpful to guide the activity and to develop learning skills during the class.
Q9	The activity modules were helpful to understand the basic concepts in class, so we could develop thinking and problem solving skills.
Q10	Each group member was knowledgeable and contributed well during the activity.

Results and Discussion

Perception of new instructional model

Figure 2 summarizes the accumulative responses of the eight survey-results in the GPMT education. The results of the accumulative responses in the surveys 1-8 revealed strong/or positive perceptions and attitudes for the new instructional model and re-designed curriculum modules in materials technology among students.

Figure 2: Accumulative Responses of the Surveys 1-8



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.28	0.12	0.15	0.07	0.12	0.18	0.06	0.14	0.14	0.17
Agree	0.67	0.74	0.73	0.72	0.70	0.75	0.75	0.75	0.74	0.71
Neutral	0.03	0.10	0.10	0.18	0.16	0.05	0.17	0.08	0.07	0.10
Disagree	0.00	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.01
Strongly Disagree	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

For example, the strong agreement was a range between 7% and 29%, and the agreement was a range between 67% and 75%, approximately. Whereas the strong disagreement was almost zero or negligible in most questions and the disagreement was a range between 1% and 4%, respectively. "Neutral" in the questions was a range between 4% and 10% in the accumulative responses of the surveys. Since active learning is generally defined as any instructional method that engages students in the learning process.[11] New instructional model and curriculum design require the students to work for meaningful learning activities and ask them to think about what they are doing in classroom.

Strong/or positive agreements (i.e., both "strong agree and agree" for Questions 1, 2, 3, and 4) are shown in the bar graphs in Figure 2. These results suggest that students could effectively learn conceptual understanding of the course subjects by these new methods as well as they would obtain some benefits (such as study preparation and problem solving skills) offered as much as by traditional learning. Since the new classroom activities developed students to actively be engaged in learning, the guided learning inquiry could result in the positive attitudes in active learning.[12]

Students, who were accustomed to traditional learning format, might be skeptical in active learning environment. However, the results of the surveys indicate that the reluctance of the new instructional approaches is reduced as time passed from the first week to the last week of quarter (Surveys 1-8 in appendix). In fact, some students felt that these methods might not be the best choice in learning.

Perception of active learning by POGIL approaches

The survey questions of Q5-Q10 are to measure the effectiveness of active learning environment for students to study materials technology using the guided inquiry. The survey results in Q5-Q10 generally indicate positive perceptions of the active learning environment implemented by the POGIL approaches, although there were the disagreements (1% to 3.8%) and neutral responses (8% to 17.3%).

Questions 6, 7, and 9 reflect the effectiveness of learning modules in class activities. Students felt they already had a strong interest in learning course materials by the learning modules. In Question 6, a total of 93% of the students agreed and only 1% disagreed that the new POGIL learning modules helped them to improve conceptual development and enhance skills in study. The most neutral (17.3%) response was associated with Question 7 about how the learning modules encouraged students towards positive attitude to work more in study. The most negative agreement (3.8%) was in Question 9, regarding to the development of the thinking and problem solving skills by the POGIL activities in classroom. Such neutral and negative responses of Q 7 and Q 9 indicate that students, who had limited experiences in active learning environment, might find some difficulty to adapt a new learning strategy to study the subjects by means of these POGIL activities.

Consider the large number of the positive agreement responses in Q6-9 that stand out strongly against the neutral/disagreement regarding the value of the POGIL based learning environment; for example, a total (11.5%) of the disagreement and neutral response in Question 9 may not be very valuable to compare to total (88%) of the strong agreement.

Perception of team learning and instructor facilitation

Questions 5 and 10 represent collaborative learning, which provides students one of the key elements to appreciate active learning environment in classroom. The results show that students generally agreed upon the importance of preparedness and helpfulness of the team members during the class activities; the total of the strong agreement and agreement in Q5 and Q10 is respectively 83% and 89%. Active learning experience can be improved by which students construct their knowledge and skills by working together. In Question 10, only small fraction of the students disagreed that they were not willing to share knowledge and skills with their team members in the class activities. Team learning (or collaborative learning) works for promoting the course goals and outcomes.

Perhaps most significantly, in Question 8, 89% of the students recognized the critical role the instructor plays in active learning, with only 2% disagreeing. This reflects the careful re-design of the course to insure that the learning module was not simply an added activity with little instructor presence.

Conclusions

- We developed optimal methods of instruction to bring desired outcomes in knowledge and skills in green materials and manufacturing technology for undergraduate students in the engineering technology programs at RIT.
- Students showed positive perceptions and attitudes for the new instructional model and re-designed curriculum modules in materials technology; among students the strong agreement was a range between 7% and 29%, and the agreement was a range between 67% and 75%, approximately.
- Students had a strong interest in learning course materials by POGIL based learning modules; a total of 93% of the students agreed and only 1% disagreed that the new POGIL learning modules helped them to improve conceptual development and enhance skills in materials.
- The results show that students generally agreed upon the importance of preparedness and helpfulness of the team members during the class activities; the total of the strong agreement and agreement is respectively 83% and 89%.
- We recognized the critical role of the instructor in classroom activities. This reflects that the careful re-design of the course is to insure that the learning module is not simply an activity, but it is to promote active learning environment to the students.

Acknowledgement

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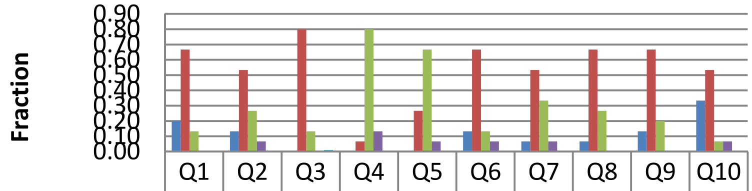
Appendix

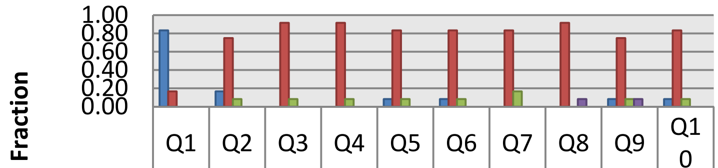
Students' surveys and data collection

Survey 1



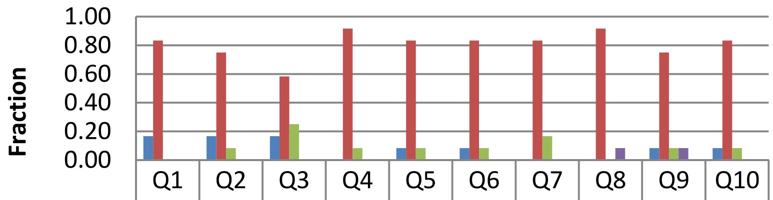
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.20	0.13	0.00	0.00	0.00	0.13	0.07	0.07	0.13	0.33
Agree	0.67	0.53	0.80	0.07	0.27	0.67	0.53	0.67	0.67	0.53
Neutral	0.13	0.27	0.13	0.80	0.67	0.13	0.33	0.27	0.20	0.07
Disagree	0.00	0.07	0.00	0.13	0.07	0.07	0.07	0.00	0.00	0.07
Strongly Disagree	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Survey 2



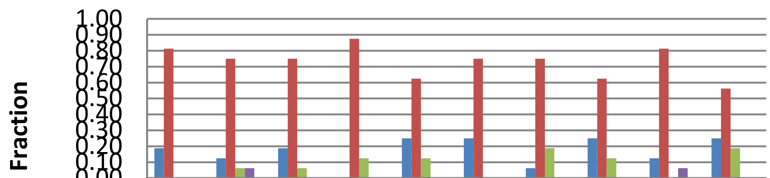
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.83	0.17	0.00	0.00	0.08	0.08	0.00	0.00	0.08	0.08
Agree	0.17	0.75	0.92	0.92	0.83	0.83	0.83	0.92	0.75	0.83
Neutral	0.00	0.08	0.08	0.08	0.08	0.08	0.17	0.00	0.08	0.08
Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Survey 3



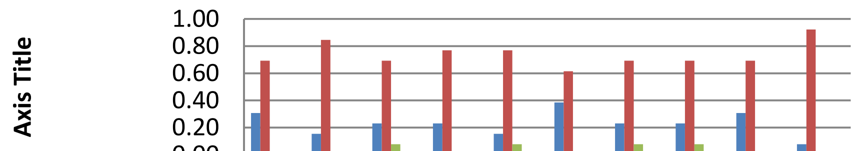
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.17	0.17	0.17	0.00	0.08	0.08	0.00	0.00	0.08	0.08
Agree	0.83	0.75	0.58	0.92	0.83	0.83	0.83	0.92	0.75	0.83
Neutral	0.00	0.08	0.25	0.08	0.08	0.08	0.17	0.00	0.08	0.08
Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Survey 4

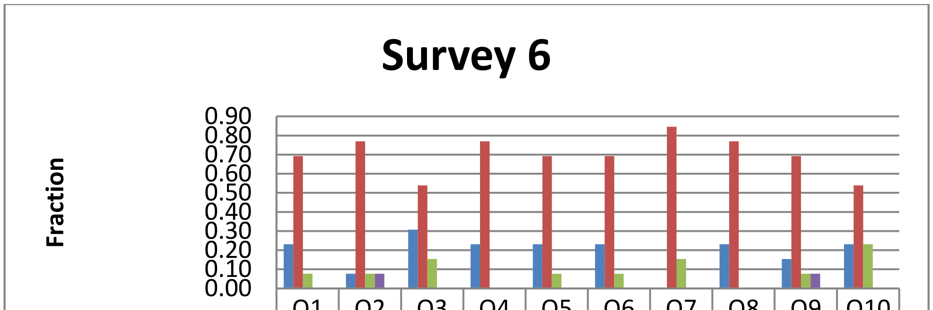


	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.19	0.13	0.19	0.00	0.25	0.25	0.06	0.25	0.13	0.25
Agree	0.81	0.75	0.75	0.88	0.63	0.75	0.75	0.63	0.81	0.56
Neutral	0.00	0.06	0.06	0.13	0.13	0.00	0.19	0.13	0.00	0.19
Disagree	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

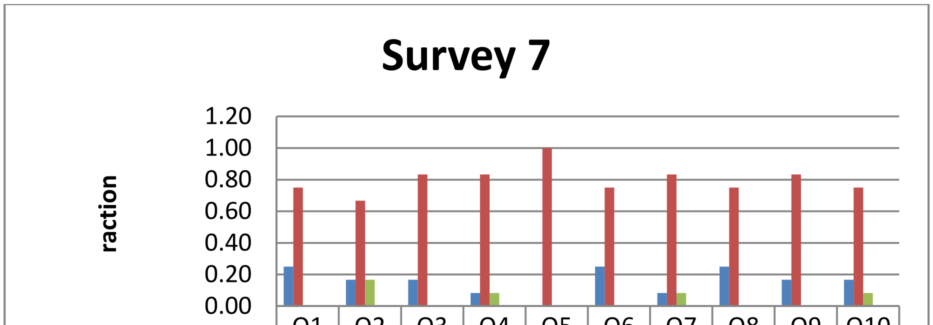
Survey 5



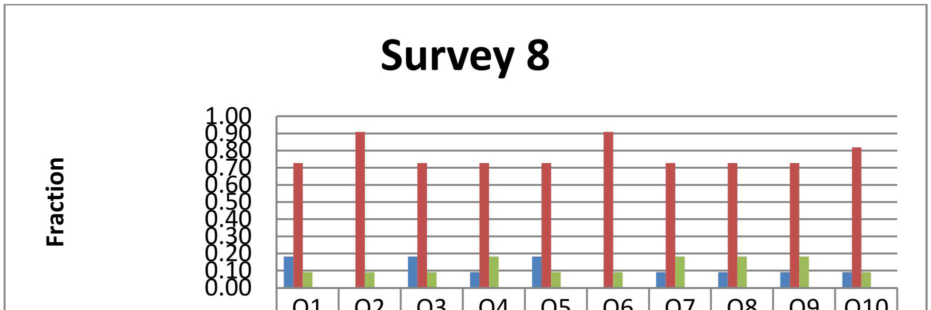
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.31	0.15	0.23	0.23	0.15	0.38	0.23	0.23	0.31	0.08
Agree	0.69	0.85	0.69	0.77	0.77	0.62	0.69	0.69	0.69	0.92
Neutral	0.00	0.00	0.08	0.00	0.08	0.00	0.08	0.08	0.00	0.00
Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.23	0.08	0.31	0.23	0.23	0.23	0.00	0.23	0.15	0.23
Agree	0.69	0.77	0.54	0.77	0.69	0.69	0.85	0.77	0.69	0.54
Neutral	0.08	0.08	0.15	0.00	0.08	0.08	0.15	0.00	0.08	0.23
Disagree	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.25	0.17	0.17	0.08	0.00	0.25	0.08	0.25	0.17	0.17
Agree	0.75	0.67	0.83	0.83	1.00	0.75	0.83	0.75	0.83	0.75
Neutral	0.00	0.17	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.08
Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Strongly Agree	0.18	0.00	0.18	0.09	0.18	0.00	0.09	0.09	0.09	0.09
Agree	0.73	0.91	0.73	0.73	0.73	0.91	0.73	0.73	0.73	0.82
Neutral	0.09	0.09	0.09	0.18	0.09	0.09	0.18	0.18	0.18	0.09
Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strongly Disagree	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Class Activity 8

Name:

Time/Date:

Group No.:

Group Members:

Background

Polymers are **organic materials***;* that is, they are composed of **hydrogen and carbon**. The **properties of polymers** are related to the **structural elements**. We study the concepts relating to the **chemical structures** of polymers.

Learning Objectives

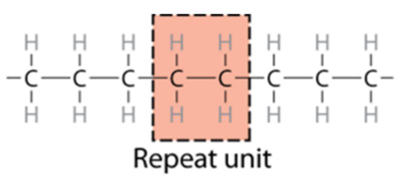
- Describe typical **polymer molecules**.
- Draw **repeat units** of PE, PVC, PP, PTFE, PS, and PET.
- Describe how small molecules transform to the solid **polymeric materials**.
- Find **applications of polymers.**

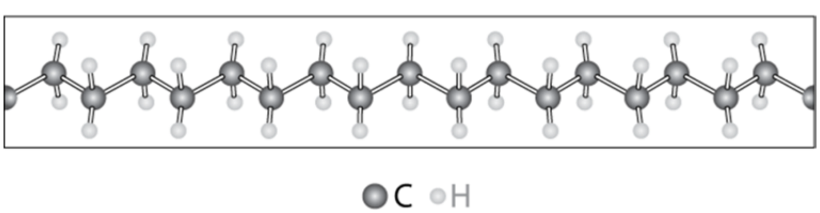
Key Terms

Define the following terms:

1. Monomer:
2. Polymer:
3. Active site:

Model 1





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Questions

1. Draw the **chemical structure** of **repeat unit** in Model 1:

2. Name the **repeat unit** in Model 1:

3. Describe the **structure of a polymer molecule** in Model 1.

4. Name the **type of bonding** formed between the atoms (i.e., interatomic bond) in Model 1:

5. Sketch the **repeat units** of the following **polymers**:
    a. PE:

    b. PVC:

    c. PP:

    d. PTFE:

    e. PS:

    f. PET:

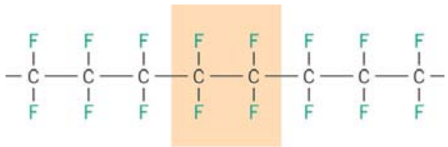
    g. PC:

    h. PMMA:

    i. PA:

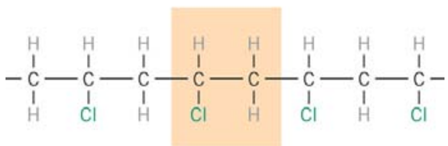
6. List **consumer products** which are mainly made out of **polymers**.
    a. ____
    b. ____
    c. ____
    d. ____

Models



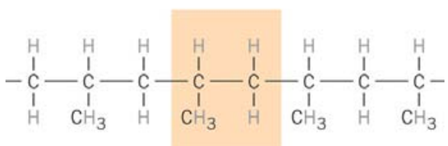
Repeat unit

(a)



Repeat unit

(b)



Repeat unit

(c)

7. Identify and name **polymer chain structure** (a):
8. Identify and name **polymer chain structure** (b):
9. Identify and name **polymer chain structure** (c):
10. On the basis of the structures presented, sketch repeat structures for (a) **polychlorotrifluoroethylene**, (b) **polyvinyl fluoride, and poly (vinyl alcohol).**

a)

b)

11. Describe how **Tetrafluoroethylene (TFE)** will transform to **PTFE**:

12. List typical **properties and applications of PTFE**:

13. List **applications** of **poly(vinyl chloride)**:
    a. ______________________________
    b. ______________________________
    c. ______________________________
    d. ______________________________
    e. ______________________________
14. List **applications** of **polypropylene**:
    a. ______________________________
    b. ______________________________
    c. ______________________________
    d. ______________________________
    e. ______________________________
15. List some reasons as **advantages** to use **polymers** over metals or ceramics.
    a. ______________________________
    b. ______________________________
    c. ______________________________
    d. ______________________________

Design Problem

1. List the **density** of PET, Aluminum, and soda-lime glass.
    a. ______________________
    b. ______________________
    c. ______________________
2. List the **melting point** of the materials listed above.
    a. ______________________
    b. ______________________
    c. ______________________
3. Compare the **relative cost** of the materials listed above.
    a. ______________________
    b. ______________________
    c. ______________________
4. What are the major **advantages/disadvantages of** plastic water bottles compared to glass or metallic bottles?
    a. ______________/______________
    b. ______________/______________
    c. ______________/______________
    d. ______________/______________
    e. ______________/______________

5. What is the **best choice of the material** for water bottle? Explain.

6. Find and describe to **manufacture** plastic water bottles using **CES Edupack**: