Polymerization Basics Activity

Cover Sheet (not for students)

Abstract

This Polymerization Basics activity was developed for Ph.D. students studying Fiber & Polymer Science (NCSU). This is an unusual course because some students have degrees in polymer science & engineering, while others have never taken a dedicated polymer course and more than half are English language learners. The activity was designed so that upon completion students will be able to: 1) define polymer terms that were included in the activity; 2) compare and contrast step growth and chain growth polymerizations, as well as addition and condensation polymerizations; 3) compare and contrast A-A/B-B and A-B type polymerizations and identify a step growth reaction scheme as either A-A/B-B or A-B; 4) describe two or more characteristics of an excellent figure caption; and 5) reflect on their group's communication and its effectiveness (or lack thereof) and be able to describe desirable characteristics of effective group communication.

Level: Graduate, Undergraduate
Setting: Classroom
Activity Type: Learning Cycle
Discipline: Polymer Science & Engineering, Materials Science & Engineering, Polymer Chemistry

Course: Advances in Polymer Science
Keywords: polymers, polymerization, step growth, chain growth, addition, condensation, interfacial, figure captions, video model

Introduction

Advances in Polymer Science (FPS 770) is a required course for the Fiber & Polymer Science PhD degree program at North Carolina State University. This is an unusual course because some students have degrees in polymer science & engineering, while others have never taken a dedicated polymer course. This course has to bring up the students with limited polymer knowledge, while not boring the students with extensive knowledge. I have tried to accomplish that through lots of peer instruction and group work--which led me to POGIL.

This is intended to be a first week of class activity. On the first day of classes we go over the syllabus, class structure, and the summary of their pre-course survey (their interests, polymer experience, etc.). Their major assignment for the semester also is introduced. This leaves sufficient time to introduce the class to our first team-based activity. We cover Q0 - Q2 on the first day (*ca*. 20 min), and then complete the remainder of the activity on the second day (*ca*. 70 min).

From the results of the pre-course survey, students are sorted by polymer science experience and then teams are formed with an effort to balance that expertise across all teams. The faculty facilitator must keep an eye on the least experienced students to make sure they are being included in the discussion and are not overwhelmed.

Students will use the activity content that is taught throughout the semester, but they will not be assessed on it *per se*. The content in this activity is review for many of the students, but new for a few. It is important for us as a class to review and get on the same page, especially in terms of vocabulary. The majority of our graduate students are international and English language learners. Learning (or reviewing) these fundamental concepts and vocabulary is particularly important due the broad diversity of educational backgrounds of the students (and that many are studying polymer science in English for the first time). Additionally, getting students to look beyond the simple definitions they learned as undergraduates is important to help them to begin to see the depth of knowledge they will be asked to explore throughout their Ph.D. studies.

Each team has a folder and a shared Google Doc with the activity. They access the activity via a laptop or tablet. The Google Doc uses “headings” so the document can be easily navigated via the “summary” feature of Google Docs (this is modeled for them on the classroom screen). At the STOP points (and sometimes at the CHECK IN points), the instructor will have the whole group share out by asking specific teams to share their results or having the teams review one another’s large wall-mounted Post-It notes. During these whole class check-ins the instructor will ask the **Process Analysts** to share something about their team’s communication (*i.e.*, what is something their team is doing well, what is something their team needs to improve on). This expectation is communicated to the class during the introduction to the activity.

Note 1: The details in **graphics in Q3** are small, especially if the activity were to be printed. Because the students access the activity via a Google Doc on their devices, they can zoom in on the graphics as needed. The graphics (in the original Google Doc) have sufficient resolution to allow substantial enlargement.

Note 2: Page breaks are used after every major (*i.e.*, numbered) question, because the breaks make it much easier for multiple people to navigate a single Google Doc simultaneously.

Note 3: We “Stop and Discuss” after **Q6** so that if time is running short, we can cut **Q7 - Q9** or choose which to answer. I do not want to cut the group discussion short if we are running out of time.

Content Learning Objectives

By the end of the activity students will be able to:

1. Define basic polymer terms that were covered in the activity.
2. Compare and contrast step growth and chain growth polymerizations, as well as addition and condensation polymerizations.
3. Compare and contrast **A-A/B-B** and **A-B** type polymerizations and identify a step growth reaction scheme as either **A-A/B-B** or **A-B**.

Processes Learning Objectives

By the end of the activity students will be able to:

1. Describe two or more characteristics of an excellent figure caption.
2. Reflect on their group's communication and its effectiveness (or lack thereof) and be able to describe desirable characteristics of effective group communication.

Welcome to FPS 770

Introduction to the Polymerization Basics Activity

We will be using team-based (*i.e.*, group-based) guided inquiry learning throughout the semester. This is our initial exercise to refresh our basic polymer knowledge and to introduce guided inquiry learning (specifically) and team-based work (in general). We will be doing ***lots*** of group work throughout the semester. You will need to be (or become) a productive and helpful team member to have a good experience in FPS 770.

Before we begin, you need to find your team and team role on the next page and physically move to sit with your team. Next, read the student roles we will use during team-based guided inquiry learning activities. Skim all of the roles, but carefully read about the role you have been assigned. Ask any questions you have about the roles!

During and/or at the end of this activity I will ask you all to reflect on the process, your assigned role, and on your team's communication.

As a class, we will **watch** this 6 minute JoVE video[1]: https://www-jove-com.prox.lib.ncsu.edu/t/10357 A transcript of the video is at the end of this document. You can access JoVE through the library. FYI, JoVE is a scientific video journal, which is peer reviewed, multi-disciplinary, and indexed in PubMed and Web of Science.

After we watch the video as a class, your team will be asked to **complete** a series of questions. Your team will be able to complete these questions based upon the video, your and your teammates' prior knowledge, and the figures included in this document. If you don't have the necessary knowledge, one of your teammates might…and that is a big reason we are working in teams!

[1] JoVE Science Education Database. Organic Chemistry II. Polymerization. JoVE, Cambridge, MA, (2022).

Preferred Name	Email	Team	POGIL1 Role
		A	Facilitator
		A	Presenter
		A	Process Analyst
		A	Recorder
		B	Facilitator
		B	Presenter
		B	Process Analyst
		B	Recorder
		C	Facilitator
		C	Presenter
		C	Process Analyst
		C	Recorder
		D	Facilitator
		D	Presenter
		D	Process Analyst
		D	Recorder

Student Roles for Team/Group Activities in FPS 770

Facilitator/coordinator

- **Make sure the team starts quickly and remains focused during the activity.**
    - “Does everyone have everything they need? Are we ready to begin?”
- **Takes care of time management.**
    - Keep an eye on the clock.
    - Keep the team on track and moving forward.
    - Communication with team members on deadlines.
        - “We only have ten minutes, that’s only three minutes per question.”
- **Makes sure all voices are heard.**
    - Address team members by name, to the best of their ability.
    - Ask team members what their thoughts are, especially if they are quiet, shy, or not on task.
        - “(Name 1), what do you think about Q2? Do you agree with (Name 2)?”

Process Analyst

- **Observe team dynamics with respect to the learning process**
    - Is everyone on the team participating?
    - Are team members actively listening to one another?
    - Are the team members being patient and respectful?
    - Are team members helping each other understand fully, rather than just giving answers and quickly moving on?
- **Report to the team periodically during the activity on how the team performs.**
    - “We are doing a great job building off one another’s ideas.”
- **Provide strengths and areas for improvement for the team at the end of the session.**
- **Be ready to report during whole class discussions about how the team is operating.**
    - Frequently, the process analyst will be asked to report on two areas your team is doing well and one area for team improvement.

Presenter/Representative

- **Communicates team questions and clarifications with Krause and/or other teams.**
    - “Can you clarify what is meant by X?”
- **Makes sure all team members are heard before asking outside sources.**
    - “Does anyone have an idea on how to address this problem before we ask for help?”
    - “Sounds like we need help. Should I ask another team or Dr. Krause about it?”
- **Represents the team during whole class discussions and the activity wrap-up.**
    - Presents the team’s ideas/answers/conclusions.

Recorder

- **Copies the Google Doc into the team’s subfolder and adds all team members’ names to the Google Doc.**
- **Records the important aspects of group discussions, observations, insights, *etc*.**
    - “This seems like an important conclusion. Let me get this into our Google Doc.”
    - “Please look at the answer I recorded for question X. Have I accurately captured our team’s discussion?”
- **The reporter’s Google Doc (in the team subfolder) is the team’s report of the important ideas and concepts the team has learned**.

Polymerization Basics Activity

Watch this 6 minute JoVE video[2]: https://www-jove-com.prox.lib.ncsu.edu/t/10357 A transcript of the video is at the end of this document. You can access JoVE through the library. Note, there is additional information included on the JoVE page.

In your teams, **complete** the following questions.

Q0

0. **Introduce yourself to your teammates**.
   - Name
   - Where you earned your previous degree(s)
   - Something you are looking forward to this semester (does not have to be academic!)
   - What you team role is and something about your role

Q1

1. As a group, complete the following:
   a. **Define** polymer

   b. **Define** macromolecule

   c. **Define** monomer

   d. **Record** your team's answers above and on the giant Post-It notes on the wall.

   e. **Discuss**: How are the meanings of polymer and macromolecule similar and how are they different? Can you think of an example of something that is a polymer, but not a macromolecule? What about the reverse? Summarize your discussion below.

[2] JoVE Science Education Database. Organic Chemistry II. Polymerization. JoVE, Cambridge, MA, (2022).

f. **Consider** the structure of a **dendrimer** (shown below). Would you classify a dendrimer as a polymer? As a macromolecule? Why or why not?

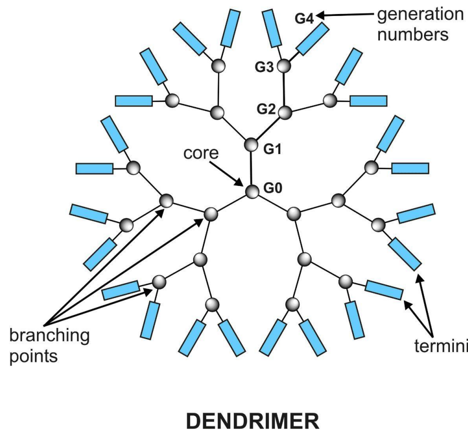


Figure 1.[3] Typical structure of a dendrimer.

g. **EXTRA**: if anyone has knowledge of how other fields use these terms, please share that with your team. Are their definitions similar or different to your team's definitions?

[3] Source: Olukin at English Wikipedia - Transferred from en.wikipedia to Commons., Public Domain, https://commons.wikimedia.org/w/index.php?curid=3864829.

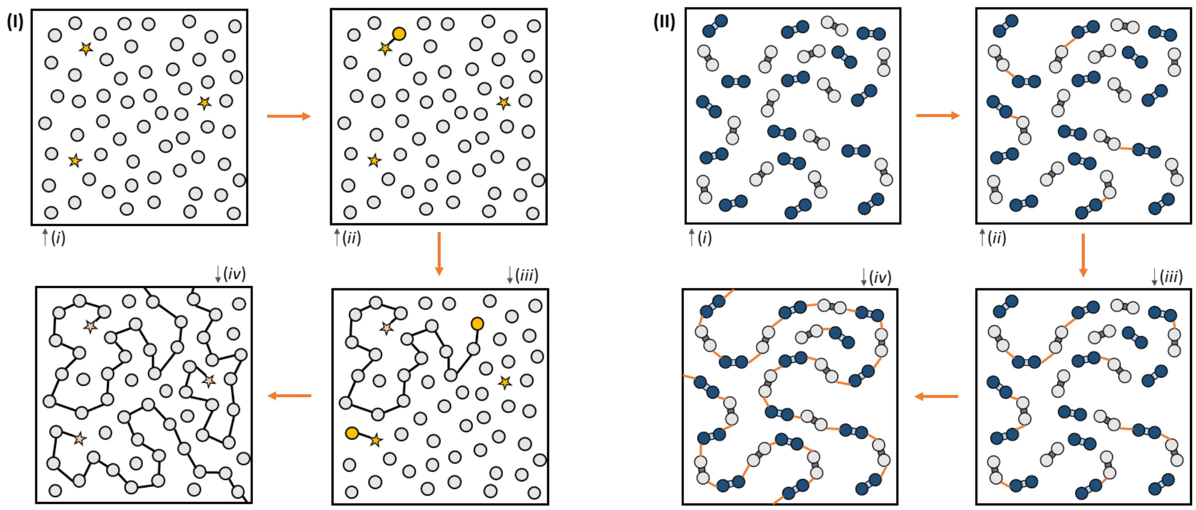
Q2

2. **In the opening of the video it states, “These macromolecules are made up of a large number of repeating units known as monomers.”** Does your team as a whole *completely* agree with this statement? Why or why not? If you don’t 100% agree with this statement, rewrite it so that everyone in your team agrees with it 100%.

Stop here. We will discuss our answers to **Q1 - Q2** as a class. Team representatives should be prepared to share out to the whole class.

Q3

3. Using the knowledge you gained from watching the JoVE video, consider the following polymerization graphics.



A. **For the graphic on the left (I)**, what do the following represent?
   a. The gray circles
   b. The black lines between the circles
   c. The yellow stars
   d. The yellow circles

B. **For the graphic on the right (II)**, what do the following represent?
   a. The blue dumbbells
   b. The gray dumbbells
   c. The orange lines between the dumbbells

C. **Label** the graphics above as either a **step growth** or **chain growth** polymerization. Before moving on, have your team representative check in with one other team to see if your teams came to the same conclusion. If not, decide if you believe your answer is correct or if you would like to revise it. You may also check in with <instructor>, if your team is having difficulty reaching consensus.

D. **Explain** your team's reasoning on how you decided which is step growth and which is chain.

E. **Imagine** the graphics above are going to be included in an undergraduate level textbook. As a group, **write** a robust figure caption(s) for these graphics. The graphic on the left is labeled **(I)** and the right is **(II)**. You may write a single caption or two separate figure captions.

F. **Reflect** on your team's answer to **3.E**. What are three or more traits of a great figure caption? Be prepared to discuss your answers with the class. (***Note,*** *you will be writing a lot of figure captions while earning your Ph.D.! It's important to think about what makes a good caption*.)

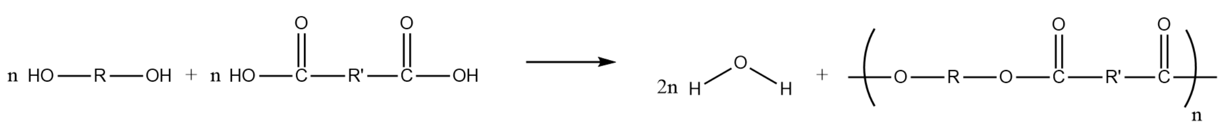
Check in with <instructor>. We may be continuing on or we may stop and share out with the whole class, depending upon timing.

Q4

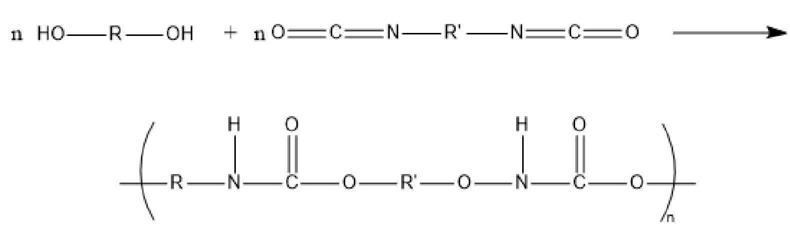
4. The video describes two different (albeit similar) ways to classify polymerizations. The first uses **growth characteristics**, *chain-growth or step-growth polymerization*. The second uses **reaction mechanisms**, *addition and condensation polymerizations*.

   A. Step-growth polymerization and condensation polymerization are often used synonymously, but they are not quite synonyms. Could either graphic (shown in **Q3**) be used as a graphic representation of **condensation polymerization**? Why or why not?

   B. **Consider** the reaction schemes below.



Scheme 1. General reaction for polyester synthesis via direct esterification.



Scheme 2. General reaction for polyurethane synthesis via reaction of a diol with a diisocynanate.

   a. Which of the reactions above can be classified as condensation reactions? Justify your team's answer in three sentences or less.

   b. Which can be classified as step growth polymerizations? Justify your team's answer in three sentences or less.

   c. Can either be described as addition or chain growth polymerizations? Justify your team's answer in two sentences or less.

C. The classification of polymerizations as addition and condensation was initially proposed by Wallace Carothers in the very early days of modern polymer science (*ca*. 1930s). Later step growth and chain growth classification was developed. Use your answer to **4.B.a-c** and prior knowledge to explain why classifying polymerizations using **growth characteristics** (*chain-growth and step-growth polymerization*) is the preferred method today.

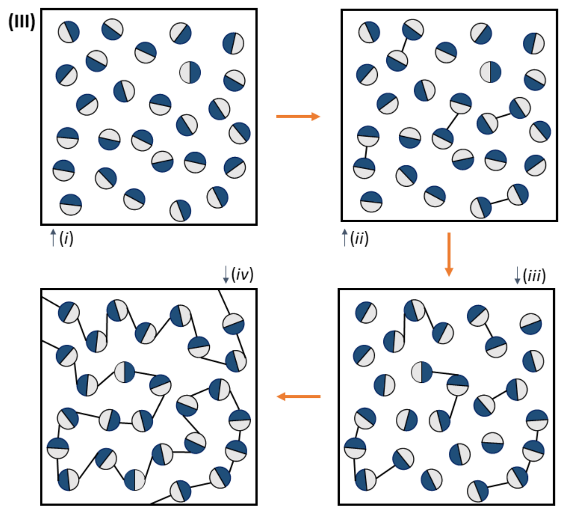
Q5

5. **Complete** the following table that compares and contrasts step growth and chain growth polymerizations. Note, you will need to use your prior knowledge in addition to what was covered in the video to complete this task. It is okay if you do not remember all of this! Hopefully, *as a team*, you will be able to complete the table without internet searches. If your team gets stuck, your team's representative can reach out to another team or to <instructor>. Facilitators, you may want to divide these tasks for time efficiency, but your team should discuss and agree on all answers.

Step Growth Polymerizations	versus	Chain Growth Polymerizations
Monomers disappear early and quickly, in favor of low MW oligomers	**Monomer Consumption**	
	Molecular Weight (MW)	High polymer appears immediately, average molecular weight doesn't change much as reaction proceeds
Long reaction times are essential to produce polymer with high average molecular weight	**MW vs. reaction time**	
	What is reacting?	The only growth reaction is addition of monomer to a growing chain with a reactive terminus
	The reaction mixture consists of…	

Q6

6. The step growth polymerization graphic in **Q3** represents an **A-A/B-B** step growth polymerization. The graphic below represents an **A-B** step growth polymerization.

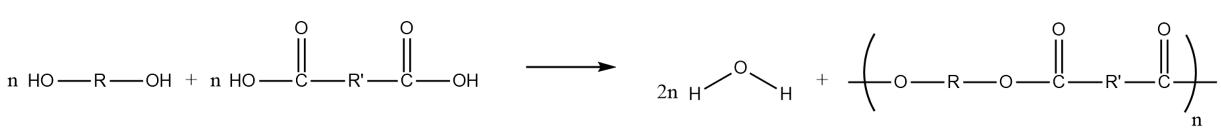


a. **For the graphic above (III)**, what do the following represent?
   i. The blue/gray circles
   ii. The blue half of the circles
   iii. The gray half of the circles
   iv. The black lines between the circles

b. **What** do the **A**s and **B**s represent when we are discussing **A-B** and **A-A/B-B** polymerizations?

c. **Consider** the polymerizations below. **Discuss** the similarities and differences of the two reactions, then **record** your team's answer below.

A-A/B-B polymerization example:



Scheme 1 (repeated). General reaction for polyester synthesis via direct esterification.

A-B polymerization example:

Scheme 3. Polymerization of an amino-acid.

d. **Define A-A/B-B** type and **A-B** type polymerizations.

e. **Imagine** your team has to create a figure for a textbook that will help explain what A-A/B-B and A-B type polymerizations are to undergraduates. You can use any graphics or reactions in this document or others that you create. **Describe** your figure (or if it is easier, your team can create the figure and paste it below).

f. As a group, **write** a robust figure caption for the figure you created. (***Reflection***: was writing a caption easier this time? Why or why not?)

EXTRA Qs (Complete as time allows.)

- Do **A-A/B-B** polymerizations result in co-polymers? What is your team's definition of "co-polymer"?
- Where does ring opening polymerization fit in? Is it step growth or chain growth? Condensation or addition? Or something else entirely?

STOP We will discuss our answers to **Q3 - Q6** as a class. Team representatives should be prepared to share out to the whole class.

Q7

7. **Consider** the polymerization (*i.e.*, the nylon rope trick) that was shown in the JoVE video. The polymerization was a “step-growth condensation reaction of polyamide using surface polymerization.” This “surface polymerization” occurs at the interface of an aqueous phase and an organic phase. These types of polymerization are more commonly called **interfacial polymerizations**.

    a. As a group, **create** a consensus definition of **interfacial polymerization**.

    b. **Record** your group’s definition on the large Post-It sheets scattered around the classroom.

    c. **Brainstorm** some applications for interfacial polymerizations. What are the **advantages and disadvantages** of using an interfacial polymerization in the application(s) your group came up with?

Q8

8. If you haven't already done so, take a few minutes to **read** the first section of the Wikipedia article on interfacial polymerization. **Discuss** how your group's definition of interfacial polymerization is the same or different from the Wikipedia definition.

    a. How is your team's definition **similar to or different from** the Wikipedia article? Did your team miss anything in your definition? If so, update your definition. Does Wikipedia need to add something to their definition? **Explain** your answer below.

    b. **Consider** Figure 2 and **answer** the following:

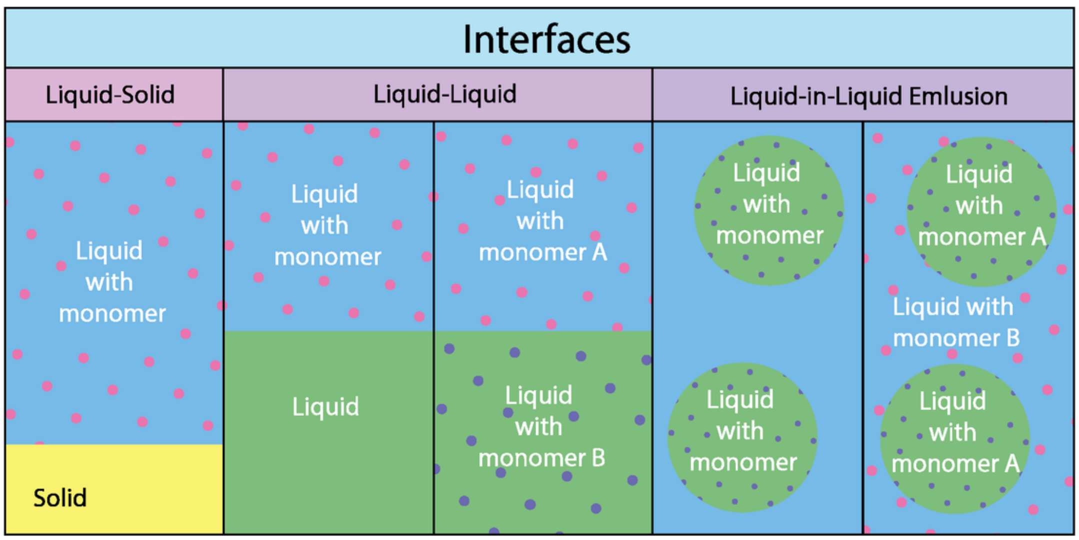


Figure 2. Interfacial polymerization figure from Wikipedia. Caption from Wikipedia: "Five common types of interfacial polymerization interfaces (from left to right): liquid-solid, liquid-liquid, and liquid-in-liquid emulsion. There are two examples each for liquid-liquid and liquid-in-liquid emulsion, either using one monomer or two." Source: Iamhumanyear, CC BY-SA 4.0, via Wikimedia Commons.

i. **Think** back to the nylon polymerization shown in the video. **Where** does that polymerization fit in Figure above? **Explain** how your team came to that conclusion.

ii. **Consider** Figure 2's caption from Wikipedia. How would you team improve the caption? **Write** your improved caption below.

Q9

9. **Reflect** on this team-based activity. **Consider** what you learned and how your team worked together and communicated, then answer the following.

    a. **Rate** your *team's ability* to:
    To effectively answer questions in this activity. **Provide** an example to support your rating.

1	2	3	4	5
Inaccurately		With some errors		Accurately

    b. **Rate** your *team's ability* to:
    To effectively communicate. **Provide** an example to support your rating.

1	2	3	4	5
Poorly		Effectively		Extremely effectively

    c. *Individually*, **rate** your confidence in being able to:
    Write an effective figure caption.

1	2	3	4	5
Not Confident		Somewhat Confident		Very Confident

    d. *Individually*, **rate** your confidence in being able to:
    Apply the content you learned/reviewed during this activity to current peer-reviewed literature in polymer science.

1	2	3	4	5
Not Confident		Somewhat Confident		Very Confident

EXTRA Q (Complete as time allows.)

- At the end of the video several applications of polymers were mentioned. **Discuss** polymer applications that you find fascinating.

We will discuss our answers to **Q7 - Q9** as a class. Group representatives should be prepared to share out to the whole class.

JoVE Video Transcript (6 min runtime):

JoVE Science Education Database. Organic Chemistry II. Polymerization.
JoVE, Cambridge, MA, (2022).

“Synthetic polymers are not only ubiquitous in everyday life, but have numerous applications across the applied and basic sciences…”

The full transcript is copied here for the students.

Polymerization Basics Activity

Solutions

Q1 Solutions

1. As a group, complete the following:
    a. **Define** polymer
    Answers will vary some. A polymer is a long, typically chain-like molecule.

    b. **Define** macromolecule
    Answers will vary some. A macromolecule is an extremely large molecule compared to typical small molecules such as solvents.

    c. **Define** monomer
    Answers will vary some. A monomer is a ~~small~~ molecule that polymerizes to form a polymer. Most students will say a monomer is a small molecule, but there are *macro*monomers. This is something I will bring up in our class discussion.

    d. **Record** your team's answers on the giant Post-It notes on the wall.

    e. **Discuss**: How are the meanings of polymer and macromolecule similar and how are they different? Can you think of an example of something that is a polymer, but not a macromolecule? What about the reverse?
    Answers will vary. Some people consider polymer and macromolecule to be synonyms. Others confine the term "polymer" to long, chain-like molecules (this is no longer standard practice). "Macromolecule" covers all large molecules. How large or long does a molecule have to be to be considered a polymer or macromolecule? That is an open question! Some say that the chains have to be long enough to entangle, but that criteria is invalid for rigid rod and crosslinked polymers.

    Proteins and enzymes are certainly macromolecules and most would call them polymers, but some don't. Every polymer is certainly a macromolecule, but there may be some macromolecules that aren't considered polymers due to their structure or chemistry.

f. **Consider** the structure of a **dendrimer** (shown below). Would you classify a dendrimer as a polymer? As a macromolecule? Why or why not?

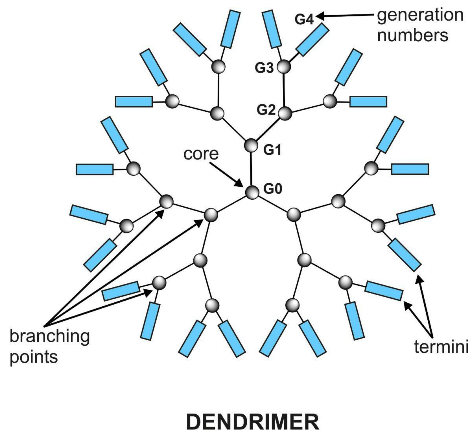


Figure 1.[4] Typical structure of a dendrimer.

Answers will vary. Dendrimers are considered to be a type of hyper-branched polymers. So they are usually considered both polymers and macromolecules. But a few people would consider them only macromolecules, because they are not chain-like and do not entangle.

g. **EXTRA**: if anyone has knowledge of how other fields use these terms, please share that with your team. Are their definitions similar or different to your team's definitions?
Answers will vary. In biochemistry, the protein subunits that form a complete, functional protein are considered "monomers."

[4] Source: Olukin at English Wikipedia - Transferred from en.wikipedia to Commons., Public Domain, https://commons.wikimedia.org/w/index.php?curid=3864829.

Q2 Solutions

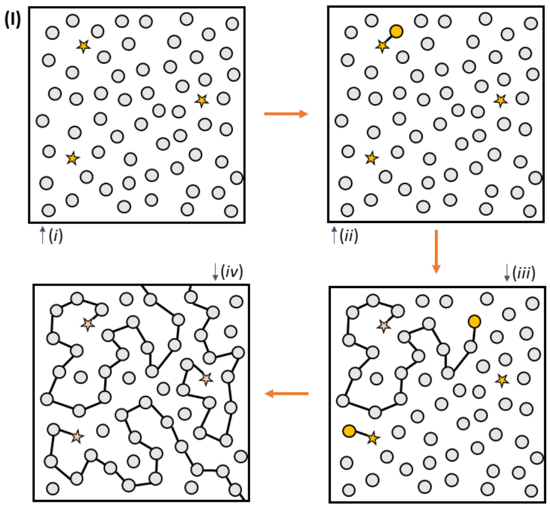
2. **In the opening of the video it states, "These macromolecules are made up of a large number of repeating units known as monomers."** Does your team as a whole *completely* agree with this statement? Why or why not? If you don't 100% agree with this statement, rewrite it so that everyone in your team agrees with it 100%.
   Answers will vary. No, we do not *completely* agree with this statement. Macromolecules are made from monomers, but once a monomer is incorporated into the macromolecule/polymer it is no longer a *monomer*; it is a monomer residue or the repeat unit of the polymer.

STOP **Stop here**. We will discuss our answers to **Q1 - Q2** as a class. Team representatives should be prepared to share out to the whole class.

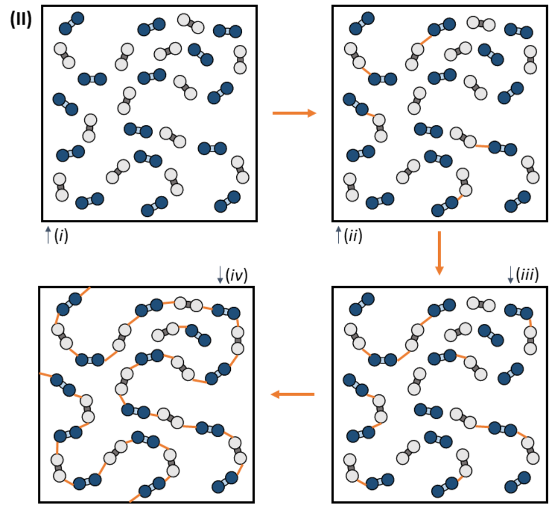
Q3 Solutions

3. Using the knowledge you gained from watching the JoVE video, consider the following polymerization graphics.

Chain Growth



Step Growth



A. **For the graphic on the left (I)**, what do the following represent?
   a. The gray circles **Monomer**
   b. The black lines between the circles **The bonds in the backbone of the polymer**
   c. The yellow stars **Initiator**
   d. The yellow circles **The active site on the growing chain**

B. **For the graphic on the right (II)**, what do the following represent?
   a. The blue dumbbells **Monomer 1**
   b. The gray dumbbells **Monomer 2**
   c. The orange lines between the dumbbells **The bonds in the backbone of the polymer**

C. **Label** the graphics above as either a **step growth** or **chain growth** polymerization. Before moving on, have your team representative check in with one other team to see if your teams came to the same conclusion. If not, decide if you believe your answer is correct or if you would like to revise it. You may also check in with <instructor>, if your team is having difficulty reaching consensus.
   See above.

D. **Explain** your team's reasoning on how you decided which is step growth and which is chain.

Answers will vary. For II, the MW builds up slowly and any blue appears to be able to react with any gray, which is typical of step growth. For I, most of the monomers are not involved and only a few chains are growing, which is typical of chain growth.

E. **Imagine** the graphics above are going to be included in an undergraduate level textbook. As a group, **write** a robust figure caption(s) for these graphics. The graphic on the left is labeled **(I)** and the right is **(II)**. You may write a single caption or two separate figure captions.
Answers will vary. **Figure X**. Representations of Chain Growth (I, CG) and Step Growth (II, SG) polymerizations. In I.i monomers (circles) and initiator are seen, while in I.ii the first monomer has been initiated and the active site is shown by the change in color from gray to yellow. I.iii Illustrates the formation of a long polymer chain and the initiation of a second chain (yellow circle represents the active site on a new monomer). I.vi shows the reaction at completion (no more chains are growing and all initiator has been consumed).

F. **Reflect** on your team's answer to **3.E**. What are three or more traits of a great figure caption? Be prepared to discuss your answers with the class. (***Note,*** *you will be writing a lot of figure captions while earning your Ph.D.! It's important to think about what makes a good caption*.)
Answers will vary. Below is a list of answers given by students the first time this question was used.
- Concise
- Clear
- Informative
- Accessible
- Explanation of each step
- Description what is happening in the picture with a key
- Good color and font
- References for figure if necessary
- description of figure symbols/colors
- description of what figure is depicting
- If the figure is a graph, the graph should be explicitly labeled and the axis should marked accordingly, and mentioned in the caption if any abbreviations are used in the figure

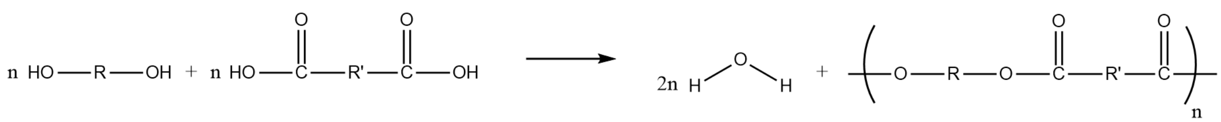
Check in with <instructor>. We may be continuing on or we may stop and share out with the whole class, depending upon timing.

Q4 Solutions

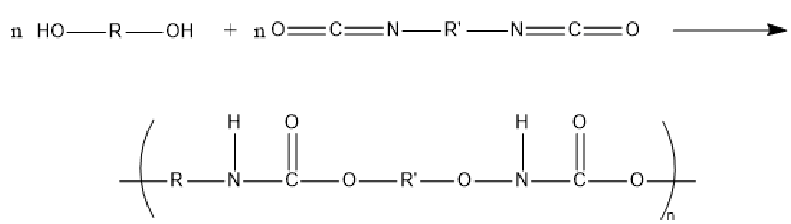
4. The video describes two different (albeit similar) ways to classify polymerizations. The first uses **growth characteristics**, *chain-growth or step-growth polymerization*. The second uses **reaction mechanisms**, *addition and condensation polymerizations*.

   A. Step-growth polymerization and condensation polymerization are often used synonymously, but they are not quite synonyms. Could either graphic (shown in **Q3**) be used as a graphic representation of **condensation polymerization**? Why or why not?
   Answers will vary. The author assumed students would answer no, because no small molecule is shown splitting out as the monomers react. But one group said yes, if the figure caption stated that the small molecule by-product is not shown--a great answer!

   B. **Consider** the reaction schemes below.



Scheme 1. General reaction for polyester synthesis via direct esterification.



Scheme 2. General reaction for polyurethane synthesis via reaction of a diol with a diisocynanate.

a. Which of the reactions above can be classified as condensation reactions? Justify your team's answer in three sentences or less.
Scheme 1. Because a small molecule is a byproduct of the reaction. Water "condenses" out of the reaction.

b. Which can be classified as step growth polymerizations? Justify your team's answer in three sentences or less.
Schemes 1 & 2. Because these reactions have monomers that react with one and other to form dimers, trimers, and other short oligomers that go on to react to form high molecular weight polymers.

c. Can either be described as addition or chain growth polymerizations? Justify your team's answer in two sentences or less.
No. Because both monomers must react to form the polymer backbone. Any alcohol can react with any acid (or isocyanate). There is no active site, which is necessary for chain growth polymerizations.

C. The classification of polymerizations as addition and condensation was initially proposed by Wallace Carothers in the very early days of modern polymer science (*ca*. 1930s). Later step growth and chain growth classification was developed. Use your answer to **4.B.a-c** and prior knowledge to explain why classifying polymerizations using **growth characteristics** (*chain-growth and step-growth polymerization*) is the preferred method today.
Answers will vary. Step growth polymerization is preferred instead of condensation because it covers all polymers made in a stepwise fashion whether or not a by-product is formed during the reaction. Chain growth polymerization and addition polymerization are essentially synonyms, so either could be used. The choice is driven by step growth.

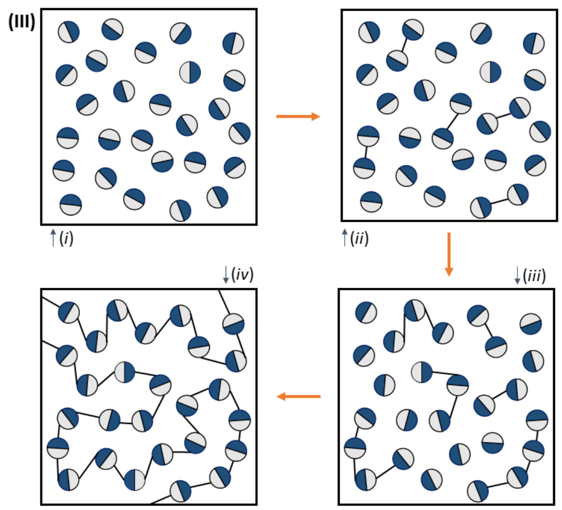
Q5 Solutions

5. **Complete** the following table that compares and contrasts step growth and chain growth polymerizations. Note, you will need to use your prior knowledge in addition to what was covered in the video to complete this task. It is okay if you do not remember all of this! Hopefully, *as a team*, you will be able to complete the table without internet searches. If your team gets stuck, your team's representative can reach out to another team or to <instructor>. Facilitators, you may want to divide these tasks for time efficiency, but your team should discuss and agree on all answers.

Step Growth Polymerizations	**versus**	**Chain Growth Polymerizations**
Monomers disappear early and quickly, in favor of low MW oligomers	**Monomer Consumption**	Monomer concentration decreases steadily as reaction time increases
Oligomers steadily increase in size, polymer average molecular weight increases as reaction proceeds	**Molecular Weight (MW)**	High polymer appears immediately, average molecular weight doesn't change much as reaction proceeds
Long reaction times are essential to produce polymer with high average molecular weight	**MW vs. reaction time**	Increased reaction time increases overall product yield, but doesn't affect polymer average MW
Reaction can occur independently between any pair of molecular species	**What is reacting?**	The only growth reaction is addition of monomer to a growing chain with a reactive terminus
The reaction mixture consists of oligomers of many sizes, in a statistically calculable distribution	**The reaction mixture consists of..**	The reaction mixture consists of high polymer and unreacted monomers, with very few actively growing chains

Q6 Solutions

6. The step growth polymerization graphic in **Q3** represents an **A-A/B-B** step growth polymerization. The graphic below represents an **A-B** step growth polymerization.

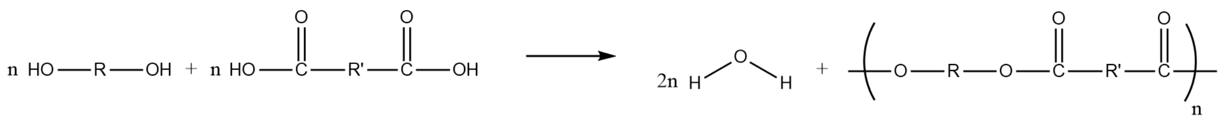


a. **For the graphic above (III)**, what do the following represent?
   i. The blue/gray circles **Monomer**
   ii. The blue half of the circles **The half of the monomer with the A functional group**
   iii. The gray half of the circles **The half of the monomer with the B functional group**
   iv. The black lines between the circles **The bonds linking the repeat units together**

b. **What** do the **A**s and **B**s represent when we are discussing **A-B** and **A-A/B-B** polymerizations?
   Answers will vary. The two functional groups that react to form the polymer chain. For example, **A** might represent an alcohol, while **B** represents an acid.

c. **Consider** the polymerizations below. **Discuss** the similarities and differences of the two reactions, then **record** your team's answer below.
   Answers will vary. **Scheme 1** has two difunctional monomers that react to form a polymer, while **Scheme 3** has one monomer with two different functional groups that can react to form a polymer.

A-A/B-B polymerization example:



Scheme 1 (repeated). General reaction for polyester synthesis via direct esterification.

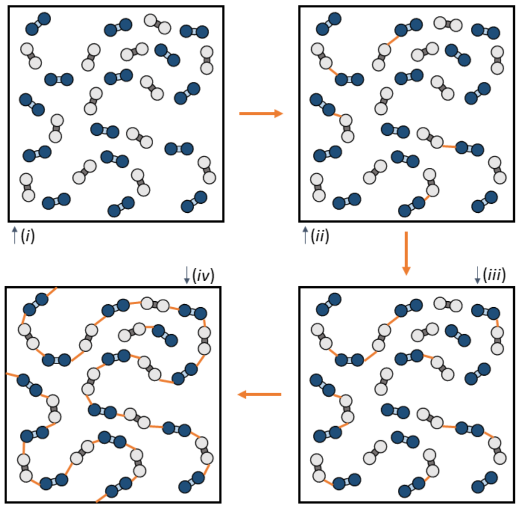
A-B polymerization example:

Scheme 3. Polymerization of an amino-acid.

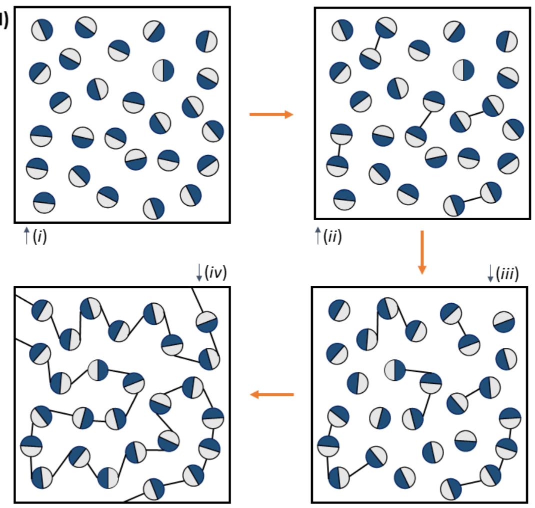
d. **Define A-A/B-B** type and **A-B** type polymerizations.
An **A-A/B-B type polymerization** is made with complementary di-functional monomers (*e.g.*, a diol reacting with a diacid to make a polyester). In contrast, an **A-B type polymerization** is made from a single monomer with two different functional groups that react to form a polymer (*e.g.*, the polymerization of a hydroxyacid or amino-acid).

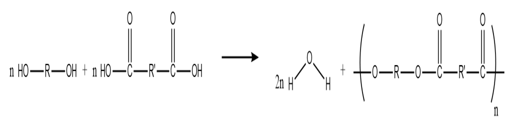
e. **Imagine** your team has to create a figure for a textbook that will help explain what A-A/B-B and A-B type polymerizations are to undergraduates. You can use any graphics or reactions in this document or others that you create. **Describe** your figure (or if it is easier, your team can create the figure and paste it below).
Answers will vary substantially. A hypothetical example is shown below.

(II)

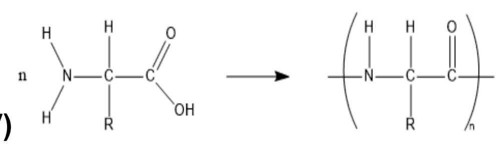


(III)





(VI)



(V)

f. As a group, **write** a robust figure caption for the figure you created. (***Reflection***: was writing a caption easier this time? Why or why not?)
Answers will vary substantially.

EXTRA Qs (Complete as time allows.)

- Do **A-A/B-B** polymerizations result in co-polymers? What is your team's definition of "co-polymer"?
  Answers will vary. **A-A/B-B** polymerizations meet the typical definition of a copolymer, but they are still considered homopolymers, because they have a single repeat unit.

- Where does ring opening polymerization fit in? Is it step growth or chain growth? Condensation or addition? Or something else entirely?
  Answers will vary. Ring opening polymerizations are typically chain growth/addition polymerizations. The mechanism of the polymerization needs to be looked at to verify the type of polymerization.

STOP We will discuss our answers to **Q3** - **Q6** as a class. Team representatives should be prepared to share out to the whole class.

Q7 Solutions

7. **Consider** the polymerization (*i.e.*, the nylon rope trick) that was shown in the JoVE video. The polymerization was a "step-growth condensation reaction of polyamide using surface polymerization." This "surface polymerization" occurs at the interface of an aqueous phase and an organic phase. These types of polymerization are more commonly called **interfacial polymerizations**.

    a. As a group, **create** a consensus definition of **interfacial polymerization**.
    Answers will vary. A polymerization that occurs at the interface of two phases.

    b. **Record** your group's definition on the large Post-It sheets scattered around the classroom.

    c. **Brainstorm** some applications for interfacial polymerizations. What are the **advantages and disadvantages** of using an interfacial polymerization in the application(s) your group came up with?
    Answers will vary substantially.

Q8 Solutions

8. If you haven't already done so, take a few minutes to **read** the first section of the Wikipedia article on interfacial polymerization. **Discuss** how your group's definition of interfacial polymerization is the same or different from the Wikipedia definition.

    a. How is your team's definition **similar to or different from** the Wikipedia article? Did your team miss anything in your definition? If so, update your definition. Does Wikipedia need to add something to their definition? **Explain** your answer below. **Answers will vary**. Most teams will not have included anything about step growth polymerization in their initial definition.

    b. **Consider** Figure 2 and **answer** the following:

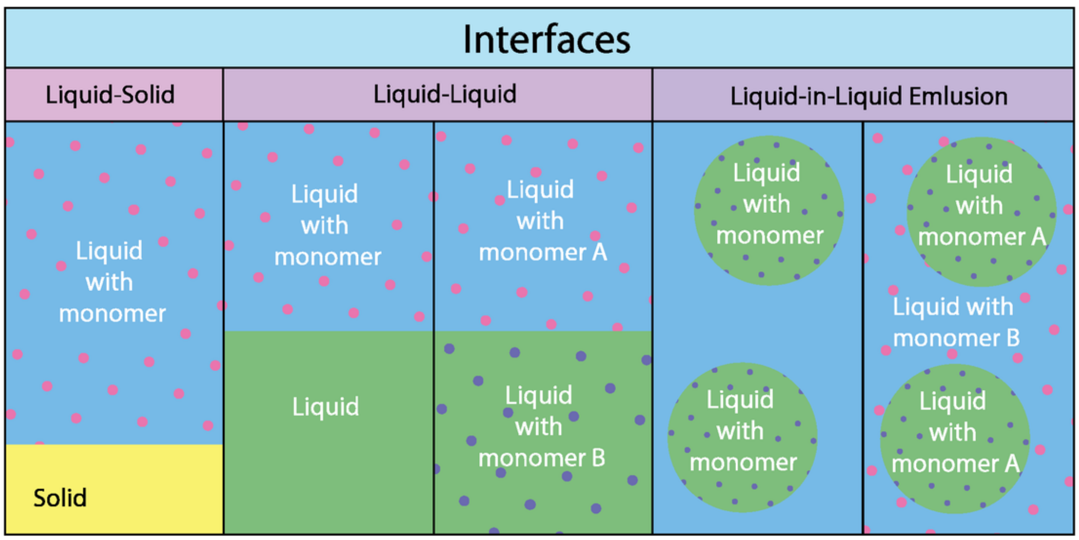


Figure 2. Interfacial polymerization figure from Wikipedia. Caption from Wikipedia: "Five common types of interfacial polymerization interfaces (from left to right): liquid-solid, liquid-liquid, and liquid-in-liquid emulsion. There are two examples each for liquid-liquid and liquid-in-liquid emulsion, either using one monomer or two." Source: Iamhumanyear, CC BY-SA 4.0, via Wikimedia Commons.

i. **Think** back to the nylon polymerization shown in the video. **Where** does that polymerization fit in Figure above? **Explain** how your team came to that conclusion. **The third one from the left.** Because the reaction used two different monomers and one monomer was in each phase.

ii. **Consider** Figure 2’s caption from Wikipedia. How would you team improve the caption? **Write** your improved caption below.
Answers will vary substantially. Teams may suggest adding an example to each type of providing more detail. Some teams might push back on this questions and state the caption is sufficient as is.

Q9 Solutions

9. **Reflect** on this team-based activity. **Consider** what you learned and how your team worked together and communicated, then answer the following.
   Answers will vary.
   a. **Rate** your *team's ability* to:
      To effectively answer questions in this activity. **Provide** an example to support your rating.

1	2	3	4	5
Inaccurately		With some errors		Accurately

   b. **Rate** your *team's ability* to:
      To effectively communicate. **Provide** an example to support your rating.

1	2	3	4	5
Poorly		Effectively		Extremely effectively

   c. *Individually*, **rate** your confidence in being able to:
      Write an effective figure caption.

1	2	3	4	5
Not Confident		Somewhat Confident		Very Confident

   d. *Individually*, **rate** your confidence in being able to:
      Apply the content you learned/reviewed during this activity to current peer-reviewed literature in polymer science.

1	2	3	4	5
Not Confident		Somewhat Confident		Very Confident

Note, when I have given this question as part of a team Google Doc, the students have *individually* answered c. & d. right on the Google Doc (several added examples, even though individual examples were not requested).

EXTRA Q (Complete as time allows.)

- At the end of the video several applications of polymers were mentioned. **Discuss** polymer applications that you find fascinating.
  Answers will vary.

We will discuss our answers to **Q7 - Q9** as a class. Group representatives should be prepared to share out to the whole class.