INSPIRED BY REAL SCIENCE

Biomedical Engineering for Breast Cancer Research in the Classroom

by Sarah Rowlinson and Karen Burg

Biomedical engineering is an exciting, blossoming field that combines the design and problem-solving skills of engineering with the medical and biological sciences to advance healthcare treatment, including diagnosis, monitoring, and therapy. Much biomedical engineering work consists of research and development, which span a broad array of subfields, such as tissue engineering, genetic engineering, neuroengineering, pharmaceutical engineering, medical devices, medical imaging, and biomaterials. Biomedical engineers work in a variety of settings, including academic and industry laboratories, surgical suites, and patient-care rooms.

One of the goals of tissue engineering is to use normal cells, taken from a patient needing an organ or tissue transplant, to grow replacement tissues and organs. Tissue engineering also aims to create cell-based systems in the lab to better understand the development of tissues and organs and the function of the cells present. These systems can then be used to test new drugs and to support scientific inquiry into disease initiation and progression. Important to designing the system is dimensionality—cells behave differently when growing in three dimensions (3-D) (e.g., in the human body) versus in two dimensions (2-D) (e.g., in a petri dish). Dimensionality of these cell-based systems is a common subject of tissue engineering research (Zhu and Nelson 2013).

The engineering-design process is the formulation of a plan to help an engineer build a product with a specified performance goal. This process involves a number of steps, and parts of the process may need to be repeated many times before the production of a final product can begin. The scientific investigation process involves systematic observation, measurement, and experimentation, as well as the formulation, testing, and modification of hypotheses. Biomedical engineering is unique because it uses both engineering design and scientific investigation techniques to create a biomedical product or add new knowledge to the biomedical field. Realizing that biomedical engineering is a hybrid of these two perspectives is key to students' understanding of the module described in this article.

This teaching module is inspired by current research being conducted by the authors: breast tissue engineering for breast cancer–research applications (Yang and Burg 2013; Booth, Park, and Burg 2013; NSF 2014). This subfield of tissue engineering aims to fabricate systems to better understand breast cancer. The introduction of biomedical engineering through implementation of this breast tissue engineering activity demonstrates to students the practices of engineering design presented in the *Next Generation Science Standards* (*NGSS*). The module distills biomedical engineering concepts, with a focus on breast tissue engineering, into a one-hour session with a hands-on activity involving simulated tissue fabrication.

The module allows students to experience the process of designing a tissue-engineered system—designing, critiquing, redesigning—and to determine necessary features for a successful system. This iterative cycle of development requires students to synthesize a host of information and tackle an open-ended problem.

Prior to being exposed to this module, students should have a foundation in *NGSS* LS1: From Molecules to Organisms: Structures and Processes (see standards sidebar on p. 58). Teachers can easily tailor this module for their individual classrooms and fit it into their curricula as they see best. Curriculum implementation is also discussed in Creating a Positive Environment for the Activity, below. This module is appropriate for students in grades 5–12.

Understanding breast tissue physiology and breast cancer

The primary function of the breasts as mammary glands is the feeding and nourishing of an infant with milk during the maternal lactation period. The breast is composed of two main tissues: glandular tissues and supporting (stromal) tissues. The glandular portion of the breast contains the lobules, which produce milk, and the ducts, which transport milk to the nipple. Each breast contains 15–20 lobes, which are composed of many lobules. The supporting tissue of the breast is made of fatty tissue and fibrous connective tissue. These supporting tissues, along with Cooper's ligaments, which underlie the muscle and bone structures of the chest and skin, are responsible for the shape of the breast (Hassiotou and Geddes 2012). The tissue-composition ratios of the breast vary among women; some breasts have larger amounts of glandular tissue than supporting tissues and vice versa (Boyd et al. 2010).

Cancer is fundamentally a disease of tissue-growth-regulation failure, in which abnormal cells show uncontrolled growth and unregulated death. This behavior can result in health problems ranging from benign breast lumps to life-threatening conditions. Known cancer risk factors include environmental/behavioral or genetic factors; however, the underlying mechanisms are still being examined by researchers. Cancerous cells can invade surrounding tissues and spread (metastasize) to distant areas of the body via the lymphatic and circulatory systems. Globally, breast cancer is the most frequently diagnosed cancer in women, with 1.38 million new cases per year. In the United States, 1 in 8 women will develop invasive breast cancer over the course of her lifetime. This disease occurs most commonly in women, but men can develop breast cancer, too. Nearly all breast cancers are categorized as adenocarcinoma, in which the disease begins in the glandular tissue of the breast (ACS 2014; CDC 2013; NCI 2014). (See Resources for more information about the breast and breast cancer.)

Pioneering work by biomedical engineers has led to advances in imaging and diagnostic tools such as mammograms, magnetic resonance imaging, and ultrasound for early detection and monitoring of breast cancer (Berg et al. 2004). There are many treatment options available for patients diagnosed with breast cancer depending on the cancer's stage, the patient's genetic profile, and the surgeon's preferences. More recently, treatment methods have been used concurrently or serially to maximize results. These therapies include surgery such as mastectomy or lumpectomy, radiation therapy, chemotherapy, and hormone therapy (Carlson et al. 2009).

This education module gives students the opportunity to participate in a healthy dialogue about a disease that affects both men and women on a global scale. The ability for students to talk freely and comfortably about this topic at a young age allows a greater sense of awareness and responsibility for one's health.

FIGURE 1 Suggested materials

Materials	Specifications
Zoob	1 250-count building set
K'NEX	Amazing Value Tub containing rods of different lengths and connectors of different sizes
Pipe cleaners	10 in. (25 cm) long, 50 count
Nontoxic modeling clay	2 5-oz. containers for each group
Yarn	Worsted or bulky yarn
Scissors	At least one set for each group
Trio Blocks	84-count building set
Colored pencils	1 set for each group
Rulers	1 for each group

Creating a positive environment for the activity

Ideally, this activity should be completed in a classroom setting with both male and female students. Lack of awareness of breast cancer is detrimental to both men and women. This is especially true of men, who sometimes ignore breast lumps and do not seek medical treatment because of embarrassment. Considering the potential immature behavior in the classroom and the general taboo against speaking about this part of the human anatomy, it may be difficult for students to concentrate and stay engaged during the activity. If this applies to your classroom, you may want to separate the sexes. This module can also be cotaught with a health teacher or guidance counselor. These adaptations allow students, especially females, to feel comfortable and speak freely about this topic.

Even when this module is conducted with a female-only group, students can initially be reluctant to use the correct vocabulary. By the end of the activity, students often become much more comfortable with discussing this disease and the role biomedical engineers play. The discussions proposed in this module lead to student empowerment by giving students the knowledge they need to be better aware of their health.

This topic may be especially sensitive for students who have a loved one with breast cancer or who have lost someone to the disease. Teachers should prepare these students ahead of time and give them the option to participate or not. If these students choose to participate, it is vital that they feel supported in however much dialogue they are willing to contribute to the discussions.

Materials

Suggested supplies cost about $5 per student for 60 or more students (Figure 1); however, alternate materials can be used. In order to maximize student creativity, no preparation or assembly is completed by the teacher prior to the activity. Providing students with different-colored, disassembled materials allows them to decide which items to use and what each item represents. All materials can be reused between classes. Therefore, five minutes are needed between classes to break down the previous class's models and return components to the "biomedical engineer's lab bench," a table that holds all the class materials needed for the activity, as shown in Figure 2. The list of materials includes basic suggestions that can be altered to meet students' skill levels. For example, students can be further challenged through "recalls" of specific materials halfway through the activity, which forces them to redesign their models and understand obstacles biomedical engineers face when conducting research.

FIGURE 2 Biomedical engineer's lab bench

Step-by-step module overview

- Prepare the classroom. Have tables arranged so students can easily work in groups of three to five. At the front of the room, have all materials spread across one table as seen in Figure 2 and listed in Figure 1. Have pencils and paper set out at each group's table.
- Begin with a 15-minute, interactive presentation using the questions provided in Figure 3 (see Introducing the Module, below). Use the figures and videos found in the References and Resources sections.
- Announce the engineering challenge and allow students to brainstorm for five minutes (see The Engineering Challenge, below). Along with the basic engineering challenge, teachers can add other design constraints (a few examples of constraints are shown in Figure 4).
- Allow about 35 minutes for students to create 2-D and 3-D models and corresponding drawings for each. Walk around the room to ensure student engagement.
- Have each group present its model. This should also be an interactive discussion. Assessment can

FIGURE 3 Questions for students

Background introduction

- What is the difference between two-dimensional and three-dimensional objects?
- What is the difference between artistic and technical drawing?
- What is breast tissue? What is the main function of breast tissue?
- Who has heard the term *cancer*? Who has heard of the disease breast cancer?
- Why have the death rates from breast cancer been decreasing over the years?
- Who has purchased a product with a pink ribbon on it?
- What is a biomedical engineer?
- How can a biomedical engineer help create a cure for breast cancer?

Hands-on activity
Think like a biomedical engineer

- Which breast tissue structures will you represent in your models?
- How many materials will you use?
- How simple or complex should the models be?
- On what scale will you make your models?

FIGURE 4 Assessment tools

Suggested design constraints

- Must contain some aspect of ductal and lobule architecture
- Must incorporate a certain number of materials
- Must incorporate a certain number of colors
- Must be under a certain weight limit
- Must be under a certain surface-area limit
- Must show structural or cellular detail
- Must have technical drawings of each model (including labels and dimensions)
- All students in each group should be able to explain their models

Example assessment questions and student responses	
Why do biomedical engineers want to create breast ductal and lobule structures in the lab?	"Because that is where breast cancer starts."
How is a 2-D model better than a 3-D model?	"2-D models are easier to make."
How is a 3-D model better than a 2-D model?	"3-D models are more like the human body, which is also 3-D."
Why is it important to have a technical drawing for each model?	"So someone from a different group can understand our model."
What can biomedical engineers do with these models?	"They can test cancer drugs on them."
Can these models be used for something else, such as studying heart attacks?	"No, because the heart and breast are very different."
Now that you've seen models from the other groups, is there anything you would change about yours?	"I would use similar materials for my 2-D and 3-D models to show how they are related."
When a woman feels a lump in her breast, what does that mean?	"It means she could have a tumor."
How do doctors diagnose breast cancer?	"Using an imaging machine [the image is a mammogram]."

be done at this time. The constraints and questions found in Figure 4 can be used to guide the interactive discussion and assessment (example student responses are shown in Figure 4). For example, does each group have a 2-D and a 3-D model that includes the lobules and ducts of breast tissue? Is each drawing closely related to the models?

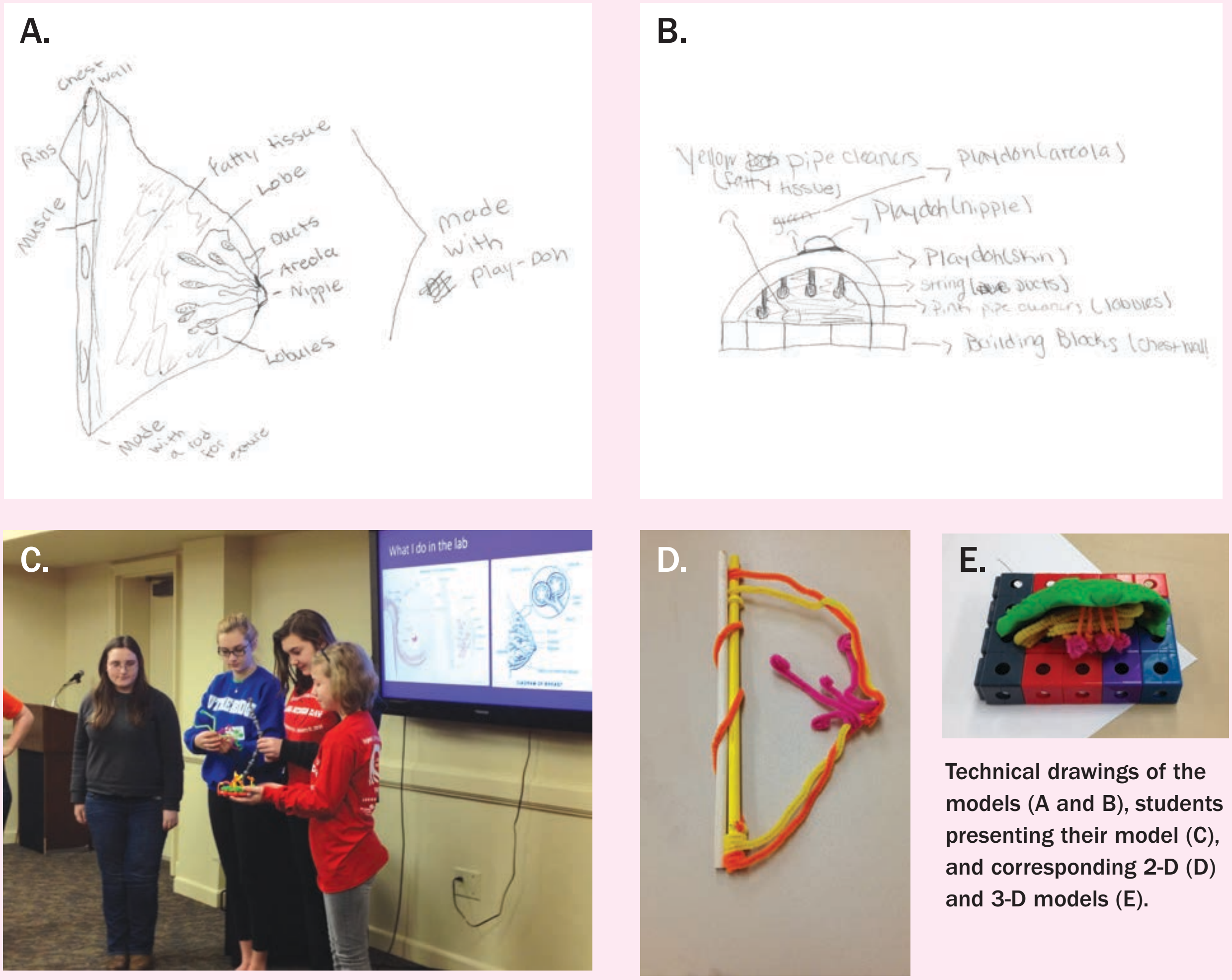
- Optional: Ask students to complete the bonus assessment (see Bonus Assessment, below).
- Allow groups to redesign their models based on peer feedback and classroom discussion.
- Wrap up module with general discussion. Answer student questions.

The timeframes discussed above are suggestions and can be modified based on student engagement and the assessment variables being considered by the teacher.

Introducing the module

When we were testing this module, we began with a 15-minute presentation introducing foundational engineering concepts for 2-D versus 3-D objects and technical drawing, as well as breast tissue anatomy and physiology, breast cancer, biomedical engineering, and breast tissue engineering. These topics satisfy *NGSS* disciplinary core idea LS1.A: Structure and Function (see standards sidebar on p. 58). The presentation is interactive; students were encouraged to respond to the questions listed

FIGURE 5 Activity overview



Technical drawings of the models (A and B), students presenting their model (C), and corresponding 2-D (D) and 3-D models (E).

in Figure 3 at the appropriate times. Students were then asked if they knew someone who has breast cancer, whether a family member, friend, or celebrity. The presentation then transitions into difficulties a biomedical engineer encounters when attempting to re-create a tissue or organ in a lab setting, such as how simple or complex the product should be and what materials should be used. We emphasized that tissue engineering research is open ended and that modeling a tissue or organ requires out-of-the-box thinking.

The engineering challenge

Once we had introduced the necessary background information and overall problem, we announced the engineering challenge. We presented students with the following challenge: As a group, create both a 2-D and a 3-D model of normal breast tissue and produce corresponding technical drawings of each model (Figure 5). When we tested this module, we added the design constraint that students needed to include the ductal and lobule features of breast tissue in their models. Students were then asked to break into small groups of three to five and brainstorm designs for their models.

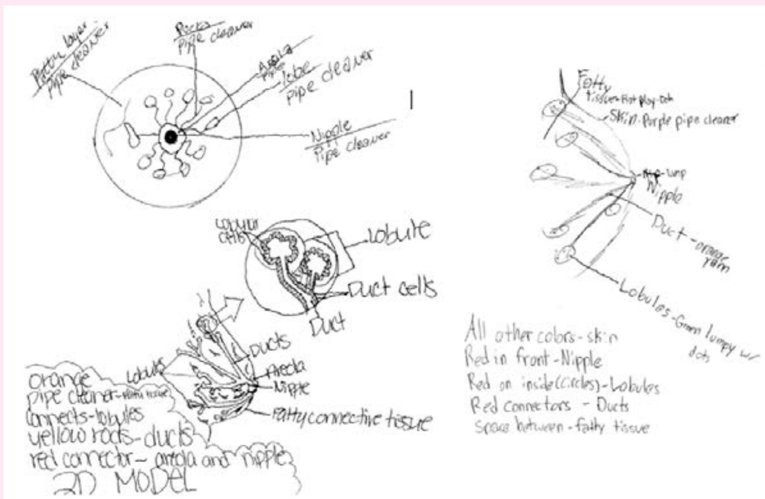
During brainstorming, students should assess which aspects of the breast tissue they feel are important to include in their 2-D and 3-D models and record that on worksheets. This decision should be guided by the information provided in the interactive presentation. Worksheets are created by the teacher and should include at least two figures of breast tissue anatomy, one depicting a front-view perspective and the other a side-view perspective. (The figures can be found in many of the items listed in the References section.)

After approximately five minutes of brainstorming, students were allowed to approach the "biomedical engineer's lab bench" (Figure 2) and take any necessary materials. The teacher then walked around the classroom to observe each group's progress and initiate individualized dialogue with students. The teacher asked students how they were approaching the challenge; whether they were working together on each portion or delegating roles; and whether they needed clarification about any of the material covered during the interactive presentation. After students made their models, they could then draw the corresponding technical drawings. The modeling-and-drawing portion of this activity required approximately 35 minutes.

At the end of the session, students presented their models to the rest of the class. This led to an interactive discussion in which students considered the strengths and weaknesses of their models and suggested improvements for their own designs, as well as the designs of other groups. Suggested improvements included making the models larger so others could better see the components, making the models more durable so they could be passed around the classroom, utilizing more colors, and spending more time on the required drawings. As shown in Figure 6, all student models properly addressed the project constraints. Each group also rendered corresponding drawings for the 2-D and 3-D models as shown in Figures 5 and 7.

FIGURE 6 Student 2-D and 3-D models

FIGURE 7 Student drawings



After student reflection through whole-class discussion, the class agreed that group prototypes should be revised to improve upon weaknesses and possibly arrive at an optimal design. Student groups were allowed to revisit their models, make changes, and discuss the rationale behind those changes. This iterative process fulfills the *NGSS* science and engineering practice Developing and Using Models. Students were again reminded why re-creating normal breast tissue in the lab is useful for breast cancer research. For example, once normal breast tissue has been accurately made in the lab, cancer cells can then be introduced into the model in order to observe cancer behavior.

Assessment tools

The questions listed in Figures 3 and 4 can be modified for assessment or evaluation and can focus on one particular subject area within the multidisciplinary field of biomedical engineering. For example, in biology classes, teachers can focus on the components of breast tissue, the function of breast tissue, and normal breast development. For a chemistry class, students can learn about the chemotherapy drugs used to treat breast cancer. In a physics class, teachers can focus on the imaging modalities used for breast cancer diagnostics.

This activity is an exciting opportunity to discuss an innovative discipline in regard to a meaningful topic.

Requirements for the technical drawings can be determined by the time allotted for the activity. Labeling each model with the anatomical structure name and corresponding material used in the 3-D model is a base requirement that can be used for a tighter time constraint. If more time is available or if the activity is completed over multiple days, the drawings can include corresponding model measurements for each structure. At the end of the module, students can present their models to and share perceived strengths and weaknesses of their projects with the rest of the class. Students should be able to describe the broader impact of engineering design and scientific inquiry on society: for example, the role of biomedical engineering in solving major health challenges that confront society today through out-of-the-box thinking.

Bonus assessment

Once all groups have finished creating their 2-D and 3-D models of normal breast tissue, assign each group a specific stage of breast cancer progression (Myal, Leygue, and Blanchard 2010): ductal/lobular atypical hyperplasia (precancerous cells that stay in the ductal or lobular lining), ductal/lobular carcinoma in situ (cancer cells fill open volume in ducts or lobules but stay within those structures), or ductal/lobular invasive carcinoma (the cancer begins in either the ducts or lobules and spreads to surrounding breast tissue). Similar to biomedical engineers introducing cancer cells into a tissue-engineered model, each group must then depict its assigned cancer stage in the model just created. This allows students to further elaborate on how a tissue-engineered model is a platform for better understanding the behavior of breast cancer. This assessment creates plentiful dialogue during the presentation portion of the activity. It also highlights the need for iterative engineering design to create a model that is easy to introduce and correctly represents breast cancer. Completion of this bonus assessment can fulfill the *NGSS* crosscutting concept Interdependence of Science, Engineering and Technology.

Why breast tissue engineering and this activity matter

Breast tissue engineering is a critical tool in helping researchers unlock the many questions related to breast cancer. As technologies continue to develop, tissue engineering techniques are being employed at even higher rates in the breast cancer–research field. The implementation of this activity has a twofold benefit: Students are introduced to the cutting-edge topic of tissue engineering, a subject not typically discussed until freshman year of college, and they become more aware of this disease. Awareness and early diagnosis are key to patient prognosis. This activity is an exciting opportunity to discuss an innovative discipline in regard to a meaningful topic and can be expanded to include the normal and disease model of other tissues and organs, such as bones, the heart, the kidneys, and the liver. ■

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References

American Cancer Society (ACS). 2014. What is breast cancer? *www.cancer.org/cancer/breastcancer/detailedguide/breast-cancer-what-is-breast-cancer.*

Berg, W.A., L. Guitierrez, M.S. NessAiver, W.B. Carter, M. Bhargavan, R.S. Lewis, and O.B. Ioffe. 2004. Diagnostic accuracy of mammography, clinical examination, US, and MR imaging in preoperative assessment of breast cancer. *Radiology* 233 (3): 830–49.

Booth, B.W., J.P. Park, and K.J.L. Burg. 2013. Evaluation of normal and metastatic mammary cells grown in different biomaterial matrices: Establishing potential tissue test systems. *Journal of Biomaterials Science, Polymer Edition* 24 (6): 758–68.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard MS-LS1: From molecules to organisms: Structures and processes		
Performance expectation MS-LS1-1: Conduct an investigation to provide evidence that living things are made of cells: Either one cell or many different numbers and types of cells.		
Dimension	**Name or *NGSS* code/citation**	**Matching student task or question taken directly from the activity**
Disciplinary core idea	LS1.A: Structure and function	How is breast tissue specialized for a particular body function?
Science and engineering practice	Developing and using models	Which breast tissue structures will you represent in your models?
Crosscutting concept	Interdependence of science, engineering, and technology	How can a biomedical engineer help create a cure for breast cancer?

Boyd, N.F., L.J. Martin, M. Bronskill, M.J. Yaffe, N. Duric, and S. Minkin. 2010. Breast tissue composition and susceptibility to breast cancer. *Journal of the National Cancer Institute* 102 (16): 1224–37.

Carlson, R.W., D.C. Allred, B.O. Anderson, H.J. Burstein, W.B. Carter, S.B. Edge, J.K. Erban, W.B. Farrar, L.J. Goldstein, W.J. Gradishar et al. 2009. Breast cancer: Clinical practice guidelines of oncology. *Journal of the National Comprehensive Cancer Network* 7 (2): 122–92.

Centers for Disease Control and Prevention (CDC). 2013. Breast cancer statistics. *www.cdc.gov/cancer/breast/statistics.*

Hassiotou, F., and D. Geddes. 2012. Anatomy of the human mammary gland: Current status of knowledge. *Clinical Anatomy* 26 (1): 29–48.

Myal, Y., E. Leygue, and A. Blanchard. 2010. Claudin I in breast tumorigenesis: Revelation of a possible novel "claudin high" subset of breast cancers. *Journal of Biomedicine and Biotechnology*.

National Cancer Institute (NCI). 2014. SEER stat fact sheets: Breast cancer. *http://seer.cancer.gov/statfacts/html/breast.html.*

National Science Foundation (NSF). 2014. Researchers aim to personalize breast cancer treatments. *www.nsf.gov/news/special_reports/science_nation/3dtissue.jsp.*

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Yang, C.C., and K.J. Burg. 2013. Designing a tunable 3D heterocellular breast cancer tissue test system. *Journal of Tissue Engineering and Regenerative Medicine.*

Zhu, W., and C.M. Nelson. 2013. Adipose and mammary epithelial tissue engineering. *Biomatter* 3 (3).

Resources

ACS: Breast cancer—*www.cancer.org/cancer/breastcancer*

Breast cancer statistics—*www.wcrf.org/int/cancer-facts-figures/data-specific-cancers/breast-cancer-statistics*

Breast cancer—Symptoms and treatment video—*www.youtube.com/watch?v=VsviAPGfPUo*

Breast cancer video—*www.youtube.com/watch?v=I2IRZuEK4Y0*

General information about breast cancer—*www.umphysicians.org/cancercare/cancer-information/cancer-library/CDR257994.html#_4*

Myoepithelium: The first line of defense against breast cancer—*http://aegiscreative.com/blog/myoepithelium-breast-cancer-expertise*

National Breast Cancer Foundation—*www.nationalbreastcancer.org*

Susan G. Komen—*ww5.komen.org*

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