3D Printing in the Classroom

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Abstract
Exposing students to emerging technologies is essential and is included in national and state standards. Yet effective methods of addressing emerging technologies are hard to find. This laboratory activity takes a very new and exciting technology, rapid prototyping and three dimensional printing, and moves it into the classroom. Based on research being conducted at the University of Illinois and elsewhere, and using light from a data projector and some simple and inexpensive supplies, student "print" objects in the classroom using techniques being developed for microstereo lithography. This activity can be effectively integrated with existing curriculum already being taught in the classroom.

Additive Manufacturing Core Competencies Covered

11A Demonstrate Proficiency in the Principles, Concepts and Applications in Additive Manufacturing Equipment

11A a5 Describe the procedures for setting up an additive manufacturing process for a part run

Introduction

Exposing students to emerging technologies is essential and is included in national and state standards. (1) (2) Yet effective methods of addressing emerging are hard to find. Often if they are addressed at all, it is through reading a passage in a textbook at the end of a unit or by showing a video once or twice a year that describes a new technology. Students are left with the belief that emerging technologies are beyond their understanding. This lack of experience with emerging technologies inhibits students from considering science and engineering as possible careers as students do not see how they could contribute to this area. Thus some students look elsewhere for possible career tracks.

This laboratory activity takes a very new and exciting technology, rapid prototyping and three dimensional printing, and moves it into the classroom. Further, it can be done without taking time away from covering all the content required over the course of the school year. This engaging lab introduces students to existing content, while doing double duty by also exposing them to an emerging technology.

This activity is based on research at the University of Illinois and elsewhere in microstereo lithography. The technology is being used by several researchers to create very small and intricate objects. The technology has been used to create objects with features as small as a few hundred nanometers.

Devices such as microbioreactors used to support biological tissue growth, and biochemical integrated chips that could simulate biological systems or be used for drug detection are being created and tested. (3),(4),(5),(6)

Overview of the Lab

In this lab, students create plastic three-dimensional objects using a photoactive polymer. A support is placed just under the surface of a polymer liquid. Blue light from a normal data projector is shined on the surface and a cross-section matching the pattern of the light is formed (see Figure 1). The support is lowered slightly, taking the first cross-section with it. Fresh liquid flows over the cross-section. The projector then shines the pattern for the next cross-section immediately on the top of the cross-section. This process is repeated until finally the entire object if made, cross-section by cross-section. (Figure 2)

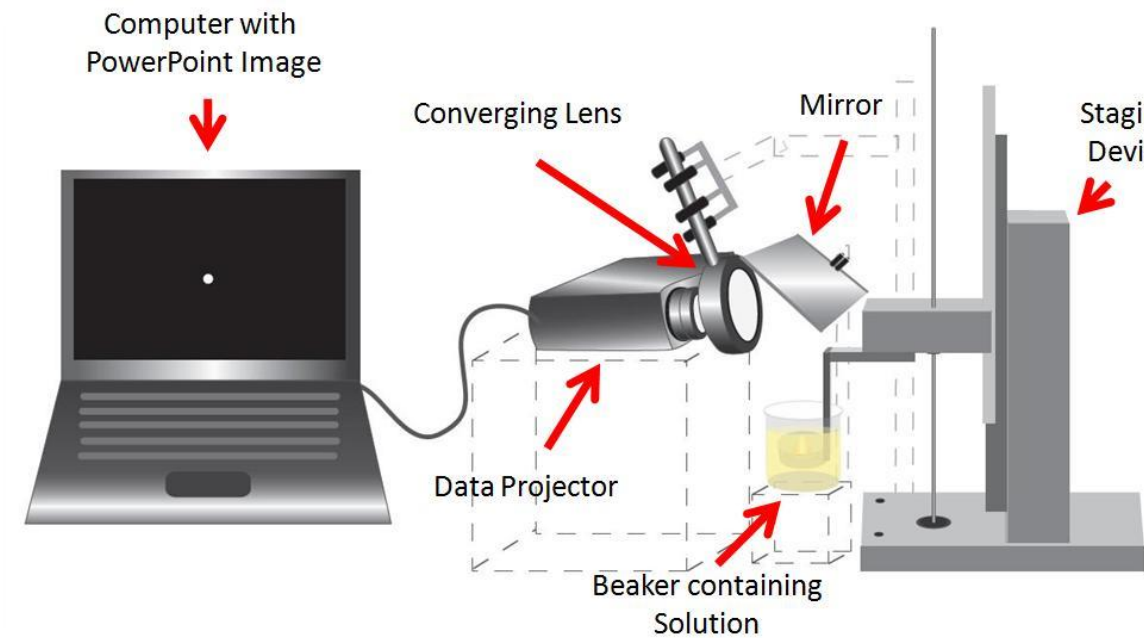

Figure 1

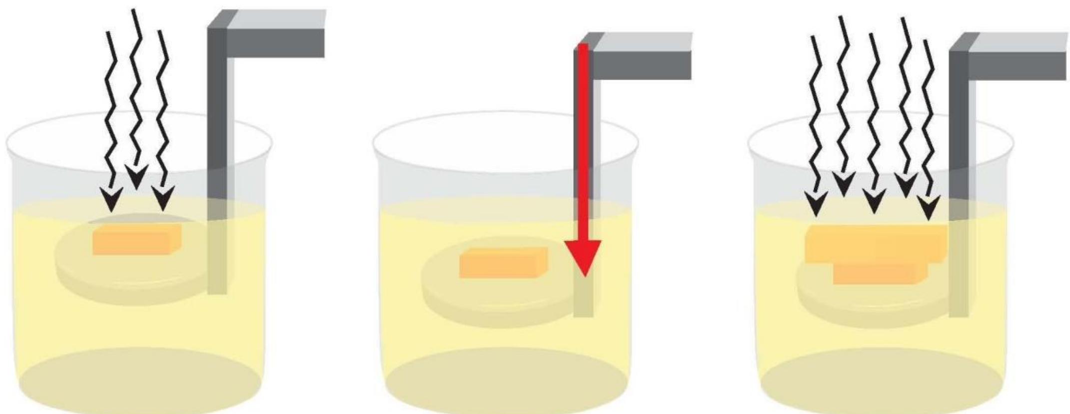

Figure 2

What is occurring chemically is that the blue wavelengths of light shone from the projector cause a photoinitiator to cleave, creating two free radicals. These unpaired electrons are looking for something to bond with. The bulk of the liquid is composed of polyethylene glycol diacrylate (PEG). This molecule has some carbon-carbon double bonds that the radicals can bond to, creating a new free radical as the double bond becomes a single bond. The new free radical finds another PEG molecule and the process repeats multiple times, creating a polymer chain, as illustrated in Figure 3. The process finally terminates when free radicals encounter each other, creating a bond with no new free radicals.

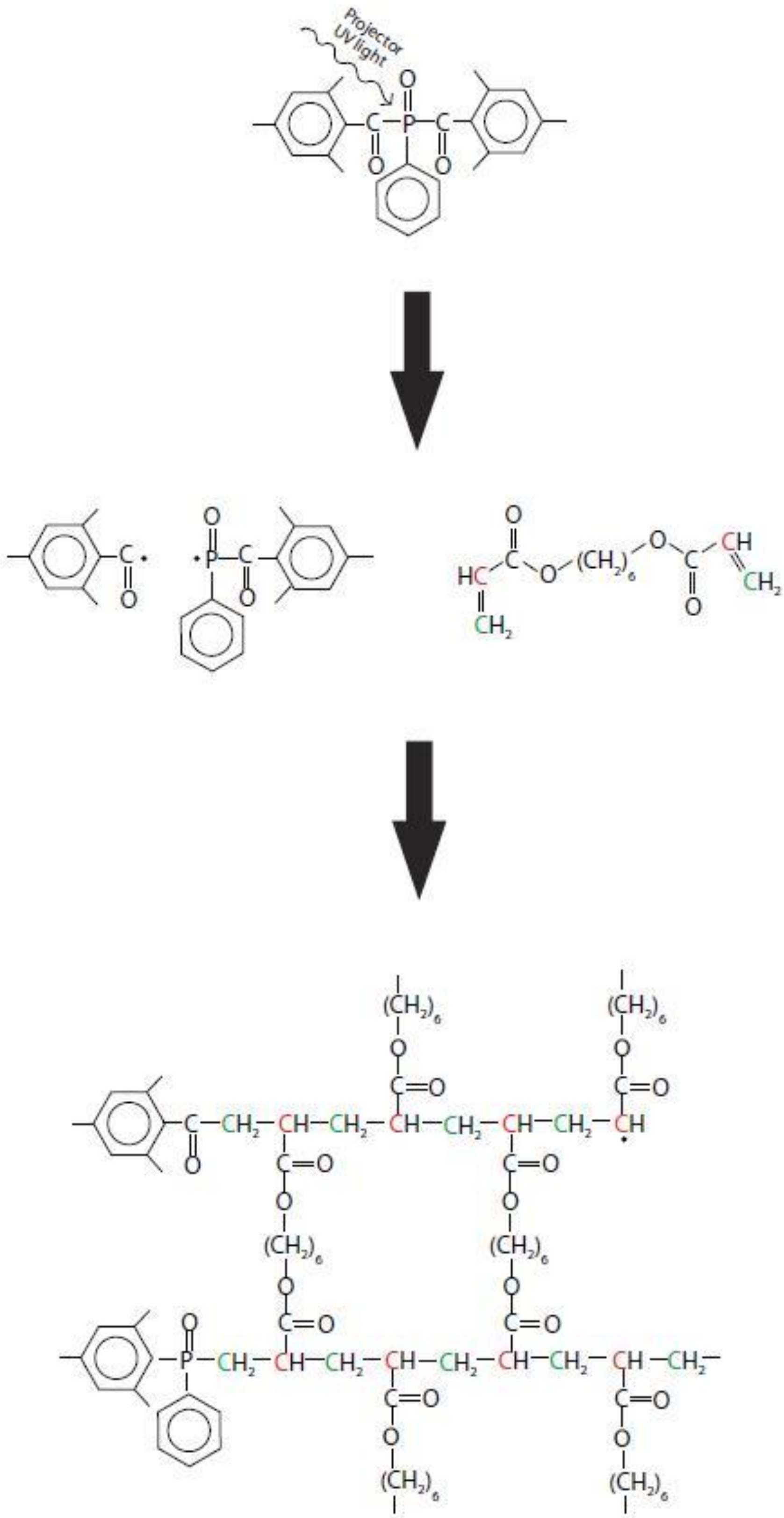
Projector
UV light

Figure 3

To mix the solution, 2 grams of the photoinitiator Phenylbis (2,4,6-trimethylbenzoyl) phosphine oxide (CAS 162881-26-7 Sigma Aldrich #511447) is added to 98 milliliters of the polyethylene glycol diacrylate (CAS 26570-48-9 Sigma Aldrich #47441). A small amount, only 0.02 grams, of Sudan I (CAS 842-07-9 Sigma Aldrich #103624) is added to the mixture as a light absorber. The light absorber allows for the creation of overhanging structures. The light will penetrate with enough energy to cleave the initiator only about 0.5mm into the beaker. This effectively means that each layer is only 0.5mm thick.

As stated above, the blue wavelengths of light from a standard data projector can be used to project the pattern of light for the cross-section. The red wavelengths of lights can be projected and not cause any reaction as they do not have enough energy to cleave the initiator. This property is useful in focusing or aligning the beaker since the red light can be projected to focus the light on the top of the liquid without causing any reaction in the beaker. Additionally, the room light is not intense enough to initiate the reaction. The process can be carried out with no special concerns for lighting.

The light from the projector is refocused with a magnifying glass. We use a plano-convex lens with a 15cm focal length from Edmund Optics (#32-975). Although we have had success with some other, less expensive lenses, this lens works very well. In front of the lens we use a front surface mirror to reflect the light down into the beaker. The front surface mirror prevents a double reflection off both the reflective surface and the glass.

PowerPoint or a similar presentation program can be used to control the pattern of light projected at the solution. Each cross-section consists of a black background with white or blue patterns representing each cross-section. In between each cross-section is a completely black slide to “turn off” the light, allowing the object to be lowered into the beaker and more solution to flow over the top for the next cross-section (see Figure 4).

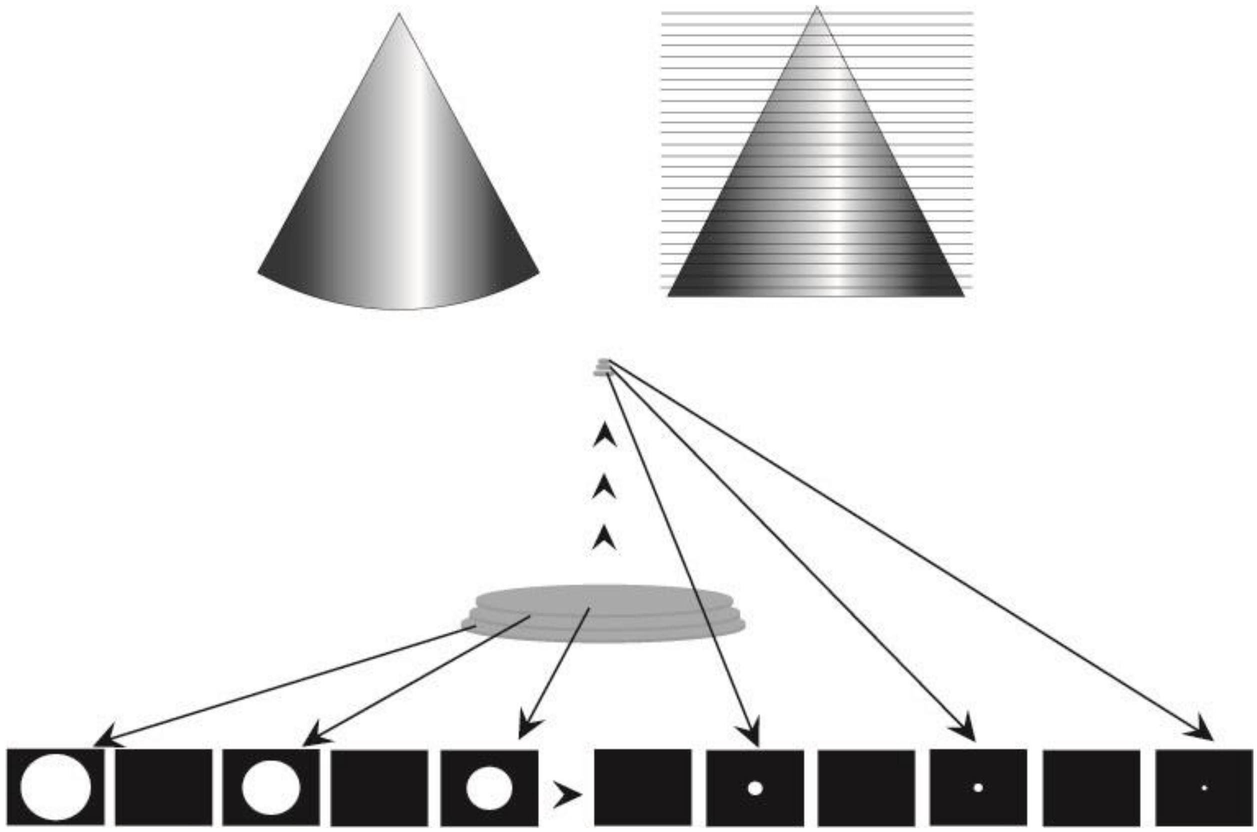

Figure 4

A support platform or "stage" is placed just under the liquid. This stage needs to be lowered into the beaker as each layer is created. We lower the object about 1/3 of a millimeter for each layer. Because the light will penetrate about ½ a millimeter, this allows overlap between layers and firmly bonds each layer to the layer below it. A simple device to lower the object in the beaker can be created with a drawer slide, threaded rod, t-nut, and a few other inexpensive items purchased at any hardware store (Figure 5).

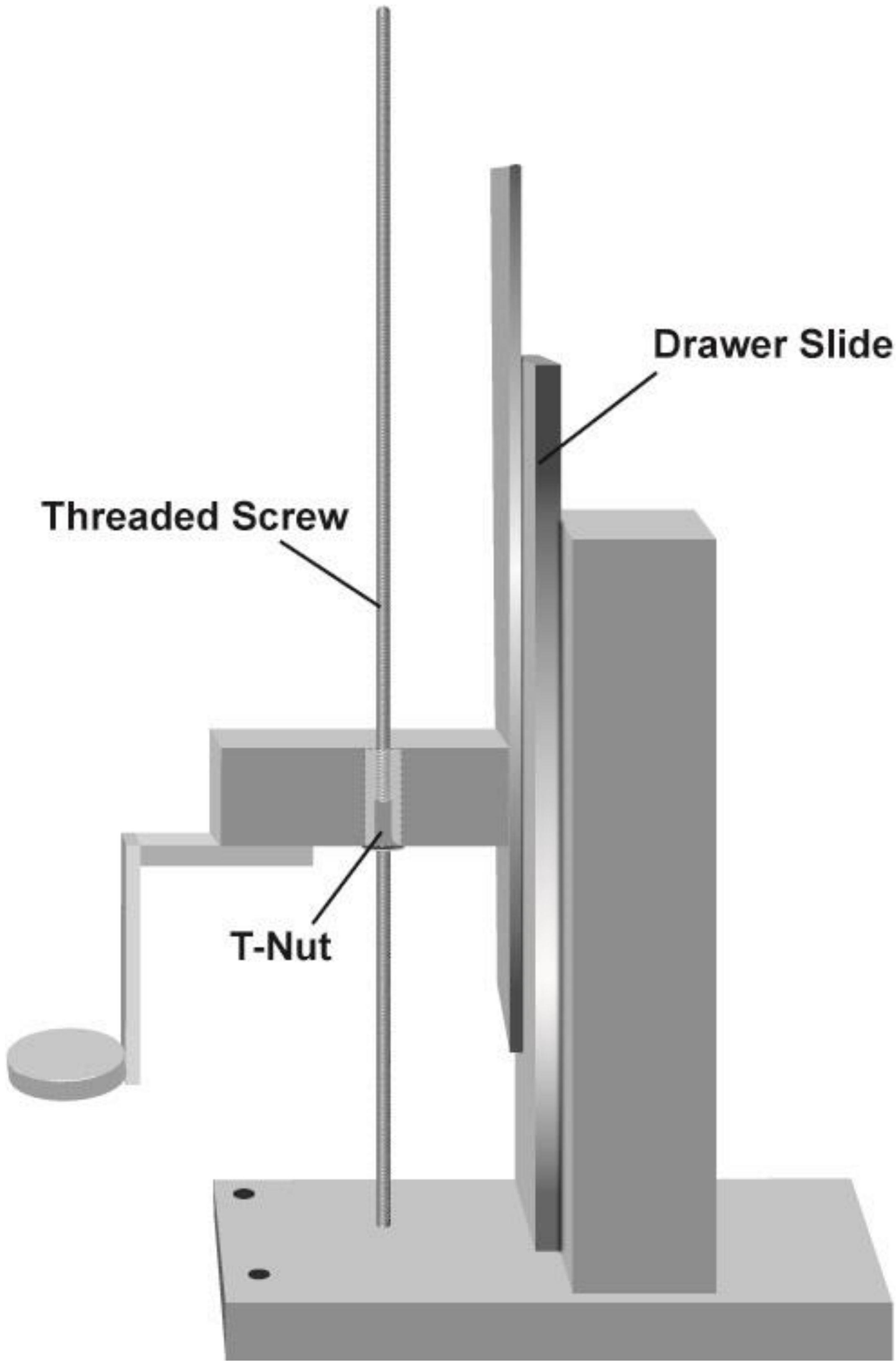

Figure 5

Complete plans for the stage as well as details for the entire process can be found at http://nano-cemms.illinois.edu/materials/3d_printing_full.html or in an article published in the Journal of Chemical Education. (7) One word of caution: in the Journal of Chemical Education article we used a different polymer, 1-6 hexanedial diacrylate, instead of the polyethylene glycol diacrylate. The polyethylene glycol diacrylate discussed in this module is much easier to work with and is thus highly suggested, especially as you first try the process.

Implementing the Activity

Students are very engaged with and excited about this laboratory activity. Creating an object with a projector seems on the one hand almost like magic, but when they understand the process and the chemistry behind it, the printing processes and science make sense to them. Students show their friends their created objects and talk about how they made them throughout the day; often the whole school is abuzz about what is happening in the science class. This is one of those activities that students will remember for a long, long time. Small Petri plates can be given out for the students to protect their objects. They gingerly take their objects home and after showing their family, they often place them on their desk or dresser as a reminder of their experience with new technology. (Figure 6)

Figure 6

In order for each student to be able to keep an object, a few different strategies can be utilized. Several print stations can be placed around the classroom. The Center at the University of Illinois has several projectors and other supplies that we loan out to set up stations for each pair of students in a class. The process can be described and students print their objects in one well-planned class period. Two objects can be created at the same time if the PowerPoint slides project the pattern for these two objects simultaneously. (see http://nano-cemms.illinois.edu/materials/3d_printing_full.html to download the PowerPoint files for several designs)

With more time devoted to the activity, students can design and create their own objects. Students first imagine what each cross section should look like for an object, then create these cross-sections using PowerPoint or a similar program. This activity, imagining what the cross-sections should look like and then creating those sections, is a good mental exercise in spatial reasoning. Students will often do this as homework since they are highly motivated to make their object (see Figure 7)

Figure 7

A strategy that allows several objects to be created quickly, yet still allows students to generate their own design consists of making objects with only a few cross-sections. "Rubber" stamps can be made quickly by creating four or five solid layers to serve as a base followed by four or five layers corresponding to the pattern of the stamp. Students can quickly customize their stamps by typing a small line of text such as their initials or by making or finding a clip art image to use. Because the light is projected off a mirror, the image is reversed. This reversal works well since when the student stamps the image onto paper, the image is reversed again and now is in the correct orientation. (Figure 8)

Figure 8

Connections to Content

This activity fits well in a chemistry, physics or physical science class. When students are first learning about chemical reactions, this reaction can serve as an example of how reactions occur. The activity is exciting for students and their resulting enthusiasm motivates them to understand the chemical processes that underlie the 3D printing process.

This lab is a clear and educationally powerful example of a reaction that is initiated by light. It demonstrates to students that heat isn't the only form of energy that can initiate a reaction. Additionally, it clearly demonstrates that different wavelengths of light have different amounts of energy. The red wavelengths do not have enough energy to initiate the reaction students experience when they shine red light to focus the light on the top of this liquid. The blue light does solidify the liquid, clearly demonstrating that the blue light has enough energy while red light does not.

Because this manufacturing platform is very open and easy to modify, this activity has the potential to work well to address engineering standards likely to immerge in the Next Generation Science Standards (2). For example, we have had students design printing stations that create the objects automatically. Motors can be used to turn the threaded rod and advance the stage, while PowerPoint advances the slides automatically. Many possible strategies exist to coordinate these two processes, ranging from simple timers started at the appropriate time to systems that obtain feedback from the computer running PowerPoint and signal when to turn on the motor. We have seen a variety of successful solutions students have created.

Acknowledgements

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On the Web

Nano-CEMMS: *http*://nano-cemms.illinois.edu/materials/3d_printing_full.html

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