Developed Curriculum for Introducing Quantum-Dots to High School Students, (Resource Exchange)

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Vahideh Abdolazimi is a PhD candidate in Electrical and Computer Engineering Department of Drexel University. She joined the Physics program of Stuttgart University joint with Max Planck Institute for Solid State Research and earned her master degree in Physics in 2014 from Germany. Her master's research was focused on fabrication and characterization of magnetic meta-materials useful for building up quantum computer devices. She started her PhD studies in 2016 at Drexel's Nanophotonics Lab. Her current research is focused on optoelectronics, fabrication and characterization of pH-dependent liquid crystal platforms with potential applications in nano-imaging systems. She was a Fellow of Drexel's CASTLE (Center for Advancement of STEM Teaching and Learning Excellence) and developed hands-on activities to teach advance engineering topics to high school students.

Jessica S Ward, Drexel University (Eng. & Eng. Tech.)

Jessica S. Ward serves as the Director of Development for the Center for the Advancement of STEM Teaching and Learning Excellence (CASTLE). During her tenure at Drexel University, Ms. Ward has successfully coordinated with multiple faculty members in the submission of approximately 700 grant proposals, including co-writing, editing and serving as the Program Manager for 9 awarded STEM education grants totaling more than $14M. She has collaborated with University offices, faculty and staff in the facilitation of recruitment strategies to increase the quality and quantity of undergraduate and graduate enrollment in STEM programs. Ms. Ward now manages the fundraising and grant writing for CASTLE and ExPERTS programs, including assisting with hiring and overseeing awarded projects as well as coordinating program evaluation.

Dr. Adam K Fontecchio, Drexel University

Dr. Adam Fontecchio is a Professor in the Electrical and Computer Engineering Department at Drexel University, and is the inaugural Director of the Center for the Advancement of STEM Teaching and Learning Excellence (CASTLE). He has held leadership positions including Vice-Dean of the Graduate College at Drexel University, Vice-Chair of the IEEE Philadelphia Section, and Associate Dean for Academic Affairs in the College of Engineering at Drexel University. His research focuses on the area of nanophotonics. He has served as PI or Co-PI on 53 funded grants with over $33M in sponsored research or foundation funding, and publication of >110 peer-reviewed articles. These metrics include both technical research and educational research/programs.

He was selected as the 2015 Delaware Valley Engineer of the Year, and is also the recipient of a NASA New Investigator Award, the Drexel Graduate Student Association Outstanding Mentor Award, the Drexel University ECE Outstanding Research Achievement Award and the International Liquid Crystal Society Multimedia Prize.

Mr. Jason Henderson, Girard Academic Music Program

A graduate of the University of Michigan (BA) and Arcadia University (MEd), I became a high school science teacher that specializes in Chemistry and Environmental Studies. I have worked for the School District of Philadelphia for over 19 years, and have spent the past 12 at the Girard Academic Music Program, a special admission school in the heart of South Philadelphia. I have worked with Drexel University as well as the University of Pennsylvania on collaborative projects, educational research, and community outreach on climate change, air quality, and STEM education.

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Abstract A Ph.D. engineering student and high school chemistry teacher collaborated to teach the concept of Quantum-dots (Q-dots) and their applications through three main stages: introduction to the topic, hands-on activity, and topic expansion. Students were *engaged* through a 5-minute introduction on “nanoscales” and “nanoparticles”. Students then made particles using a dye-gelatin mixture to *explore* fluorescence effect in macroscopic dots, a similar optical phenomenon in Q-dots at nanoscales. Instructors explained the concept of fluorescence as a quantum kinetic in nanoparticles, which *expanded* the lesson through the theoretical discussion of Q-dots and the applications of fluorescent Q-dots in contrast-enhanced biomedical imaging systems.

Introduction Quantum dots are nanometer (nm)-sized particles, typically less than 10nm in diameter [1], composed of semiconductors which have been proven to be powerful probes for fluorescence imaging [2]. Fluorescence is a physical phenomenon in which a chemical compound emits light of a particular color very shortly after being hit by light of another color [3] and is an important tool used in the biotechnology laboratories. Fluorescent molecules can be used directly or attached to other molecules to determine the locations of certain structures or an/a activity/parameter (such as pH) within the cell [4]. Q-dots have been developed as fluorescent assays for contrast enhanced biomedical imaging, such as tumor imaging and therapy [1-2, 5].

Lesson Objectives

1. Introducing Q-dots as an advanced concept in chemistry/materials engineering
2. Enhancing the students’ understanding of particle sizes and Q-dots as a type of nanometer-sized particle
3. Engineering macroscopic dots with fluorescence properties
4. Expanding on the fluorescence effect as one of the important optical characteristics of some manufactured Q-dots
5. Exposing the students to new techniques in contrast-enhanced biomedical imaging exploiting fluorescent Q-dots

First Stage: Engagement Students were engaged in the topic through a 5-minute introduction on Nanoparticles. The terms “macro” and “nano” were introduced. A comparison of sizes between objects such as a ball, marble, dust, and dye molecule were made through slide shows (Fig.1 supp. [6]) to help students improve perception about macro- and nano- particles and its math. The students were then exposed to the term “Quantum-dots” by showing them a picture of a mouse with Q-dots in its body (Fig.3 in supp.). Students exchanged ideas of what the picture may illustrate from their own perspective during a 3-minute brainstorming discussion. Further explanation about Q-dots and its applications were made in the last stage of the lesson.

Second Stage: Exploration A hands-on activity was designed for the students to engineer macro-particles (macro-dots) with controlled sizes and florescence effect. This demonstration aimed to lead the students to an understanding of a similar optical phenomena exhibited by much smaller particles, specifically Q-dots. Though Q-dots are not individually visible to the human eye their presence can be identified by the light they emit.

Activity Description Students in pairs of two performed the following demonstration procedures for 15 minutes during class (printed worksheets were provided). This is a low-cost activity that can be done with a budget ranging between 10-25 dollars for a class of approximately 30 students depending on the available resources, Fig.2 supp.

Materials The following list of materials are required for each group: Beaker 200 ml or foil cups (one); Cups, straws/dropper, petri dishes (one of each); Ice cubes (as much needed to fill the beaker); Fluorescent dye (a few droplets); Gelatin/Agar (1 gram); Vegetable oil (a few spoonful); UV (Black) bulbs and lamp or LED UV flashlights can be used alternatively (one of each).

Demonstration Procedure*:*

1. Put a few ice cubes inside a beaker. Place a petri dish on top of the ice cubes. Pour a few tablespoons (~2-5 ml) of frozen oil into the petri dish. Pour 1 gram (1 teaspoon) of gelatin into the cup and add 10-15 ml hot water into it. Stir it until the powder dissolves entirely into the water. Add a few droplets of the fluorescent dye into the mixture.
2. Take a straw and place one end of it into the gelatin blend. Put your finger at the other end; a droplet of gelatin mixture will remain inside the straw. Take the straw end out of the gelatin container and steep it into the oil in the petri dish. Release your finger to free the droplet into the oil. You can control the size of particles by controlling the amount of gelatin you release in the oil. Try to drop enough of the mixture to allow the dots to form in the oil without spreading. Repeat this step a few times to form a few droplets of the gelatin mixture inside the petri dish. Do it quickly before the gelatin blend solidifies in the cup.
3. Darken the room. Turn on the black light and shine it to the droplets.

Third Stage: Expansion In the first 5 minutes of this stage students discussed their observations made during the activity. They exchanged their hypothesis around the color shift phenomena in the macro-dots upon illumination with white light compared to the black light. In the next 15-20 minutes the instructors used power-point slides to explain the fundamental concepts and phenomenological effects that were explored. Furthermore, the topic was expanded by introducing applications of Q-dots in biomedical engineering.

First, students were introduced to light as an electromagnetic wave which carries energy and has a spectrum consisting of seven distinct regions including visible and UV. Wavelength was explained to provide background on why visible light can represent different colors and energies. Second, Quantum-dots were introduced as a few nanometer-sized particles (nano-dots). Their light interaction properties can be formulated using Quantum Mechanic laws (defined as a different set of physical laws than Newton's) and, thus, are named Quantum-dots. Third, the fluorescence effect was demonstrated through some animations which showed how excitation of electrons in Q-dots by a light with particular wavelength and energy can result in emission of another light with a different wavelength and energy, hence representing a color shift to human eye. These discussions finally led to the expansion of the "Fluorescent Quantum-dot" concept as novel assays for contrast-enhanced biomedical imaging. The figure which was shown primarily to drive the students' attention in the first stage was shown again to demonstrate how scientists exploit the fluorescence effect in Q-dots to image tumor sites in a mouse with significantly better contrast. The image illustrates fluorescence radiation of a circulating Q-dot solution in the mouse body where fluorescence intensity gradient (in the processed image) indicates the tumor region [7].

Supplement I: Figures

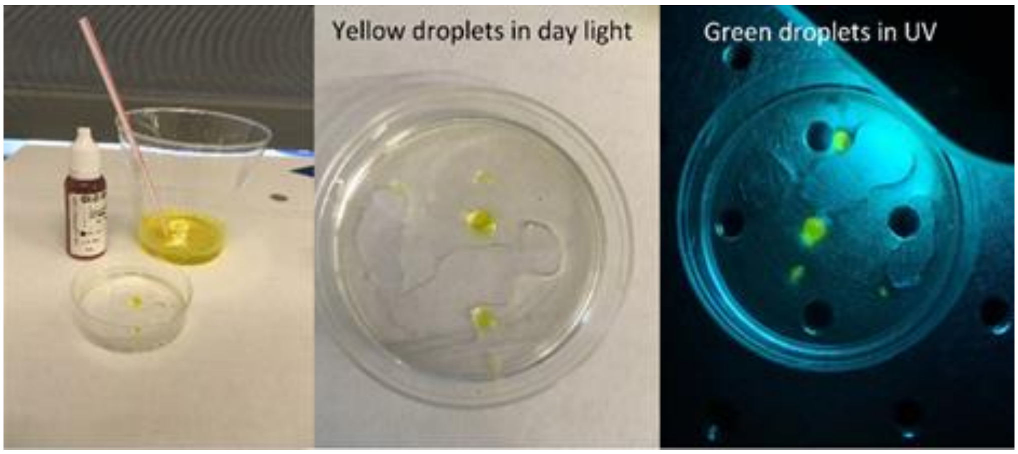

Figure 1, Using straws, students made dot shape droplets (marco-dots) of gelatin-dye solution in a petri dish containing oil and floated on ice. Droplets with 0.5cm diameter or smaller displayed yellow and green colors under day light and UV light, respectively, due to fluorescence effect.

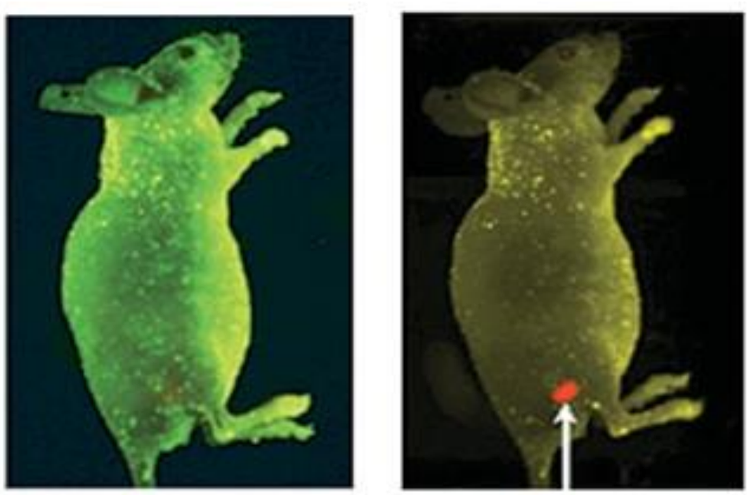

Figure 2, In vivo fluorescence images of tumor-bearing mice using Q-dot assays, left) as-detected fluorescence radiation, right) processed image (spectral un-mixing), the arrow points the tumor site. Image may be subjected to copy-right permission [7].