

# CONNECTING ARTISTICALLY-INCLINED K-12 STUDENTS TO PHYSICS AND MATH THROUGH IMAGE PROCESSING EXAMPLES

*Gail Rosen\**, *Jason Silverman†*, and *Adheer Chauhan\**

Drexel University, Philadelphia, PA 19104

<http://dk12.ece.drexel.edu>

## ABSTRACT

Our goal is to use the context of image processing to stimulate interest and, ultimately, develop students' understandings of the math and science concepts in the K-12 classroom. The paper will present ideas to the signal processing community on how image processing can connect directly to standard curricular concepts. Since many teachers are confined to set-curricula, this can limit the scope of illustrating more advanced DSP concepts in the high school classroom. Ultimately, the goal is for students to conduct their own inquiry and to understand the principles behind artistic tools while learning math and science. This paper presents the development of image processing tools that will be tested throughout the 2008-2009 school year.

**Index Terms**— Image Processing, K-12 Education, Edge Detection,

## 1. INTRODUCTION

Recently, concepts from digital signal processing have been incorporated into the high school classroom through specialized engineering education [1, 2, 3]. Yet, there are many DSP applications, such as image and sound manipulation, that can connect students to basic math and science concepts as well [4, 5]. We aim to show that DSP is a perfect cross-disciplinary bridge since it has a breadth of applications that impact the liberal arts and scientific community alike [6]. We propose that image processing can serve as a vehicle to connect artistically-inclined students to STEM (science, technology, engineering, and mathematics) through their multimedia interests, and, ultimately, help them to understand important science and math principles. This paper will focus on discussion of the tools developed and an initial qualitative test-run conducted on K-12 students.

The National Council of Teachers of Mathematics (NCTM) standards documents [7, 8, 9, 10] call for teaching mathematics for understanding where students “actively build new

knowledge from experience and prior knowledge” ([10], p. 20). The initiatives of these and science organizations have attempted to fundamentally change what it means to learn STEM. Instead of memorizing techniques and algorithms, they envisioned that students develop mathematical power: “[the] ability to explore, conjecture, and reason logically, as well as the ability to use a variety of mathematical methods effectively to solve non-routine problems” ([7], p.5). Inquiry-based instruction encourages students to develop such understandings, where students investigate legitimate questions, hypothesize about solutions, then generate, discuss, and evaluate the solutions positions.

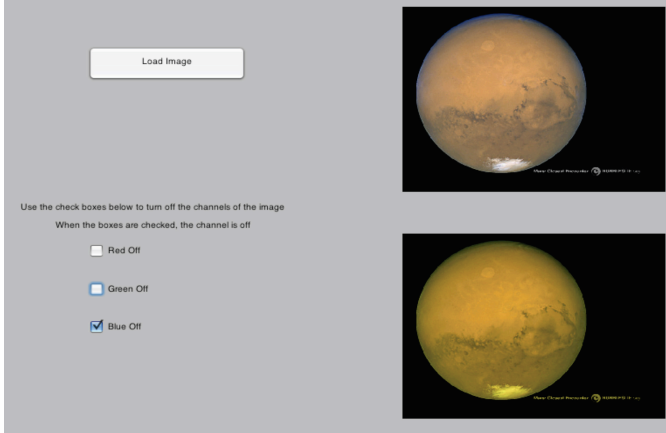
While most university project's ignore the NCTM standards, an image processing project successfully taught pixel-related arithmetic to middle-school students in the classroom [4]. Interestingly, when they went beyond arithmetic, they expressed difficulty in relating complex mathematics such as image warping, and while students were intrigued and understood the applications (which is noble in itself), they obtained little curricular content. Through DSP applications in the classroom, an advantageous by-product is that students will get a sense for the associated real-world applications of the activities. In this paper, we suggest activities that will adhere to standard high school curricula while explaining image processing applications and ideas.

## 2. TARGET: ARTISTICALLY-INCLINED STUDENTS

Our partner school is the Philadelphia School for the Creative and Performing Arts (CAPA), and our project's goal is to connect these students to science and math through their creative interests. As of 2006, CAPA 9th- and 10th-grade students score higher than the national average at or above 90% in reading and language, but at 83% and 73% in math and science, respectively. So, while students at the school are very good, there is approximate 22% disparity between their language arts and math/science proficiency.

It is also hypothesized that some artistically-inclined students rule out STEM (Science, Technology, Engineering, and Mathematics) careers due to their creative passions. Although the activities of scientists and artists differ, they share in common “the creative process and the synthetic thinking” [11] to

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**Fig. 1.** Subtractive color model interface to illustrate RGB . By turning off the blue channel, the red and green still shine through creating the effect of making Mars more yellow.

achieve the desired goals. STEM and the arts have always been seen as disparate fields, and this project aims to bridge this connection by using image processing as a vehicle to instill a deeper interest in STEM-related concepts.

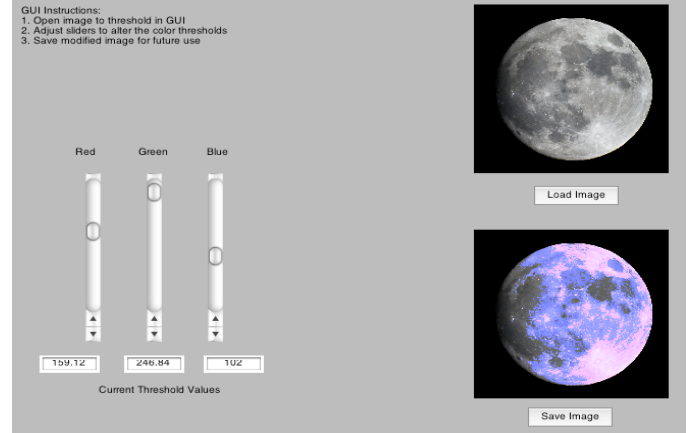
### 3. LABORATORIES

In this section, we state the physics and math concepts that our image processing exercises can illustrate. Instead of creating examples to illustrate DSP concepts, our goal was to develop a lab around a particular curricular concept into a lesson. Through image processing examples, the students will learn about curricular concepts. Of course, the by-product is that this will lead students to understand how these curricular concepts are applied.

#### 3.1. Physics and Linear Piecewise Operators: Illustrating RGB Light

In physics, students learn about the light spectrum and their corresponding wavelengths. In art, students learn about mixing primary pigments (yellow, blue, and red) to make new colors. The primary colors of light, red, green, and blue (RGB), are rarely taught, although almost every student has watched a TV or used a computer, which uses the RGB spectrum. There are two ways students can learn about light color composition: 1) a additive or 2) a subtractive color model. The additive model can seem more intuitive to the student at first, and the subtractive version (where a student turns off a channel) forces students to think inversely. An example of the subtractive color model interface is illustrated in Fig. 1.

Students can also combine the RGB color shades they learned about with a thresholding operator. Thresholding is a nonlinear operator where above a particular number, the pixel-intensity is expressed, otherwise, it is off. In RGB, this



**Fig. 2.** Students now use thresholding (linear piecewise operator) on each channel to create color graphical effects on an image.

is applied to each of the colors and the operator on each channel is expressed as a nonlinear operator in a piecewise function:

$$y_c = x, \quad x \geq \text{threshold} \quad (1)$$

$$y_c = 0, \quad x < \text{threshold} \quad (2)$$

where  $c$  is either the red, green, or blue channel. Building upon the RGB exercise with the linear piecewise functions can provide students with another context of how to apply math and science concepts – in this case, the student can highlight different intensities of the moon in different colors, as seen in Fig. 2.

#### 3.2. Mathematical Statistical Operators: Image Denoising

Ninth grade students learn about statistical operators on a number, such as taking the mean and median. Usually, students are given a motivational example, the distribution of their grades, and compute the mean and median on these numbers to gain a sense of their meaning. In our activity, we aim to show the mean/median's ability to remove noise in corrupt images. Students are introduced to Gaussian and Salt and Pepper noise, where each can be caused by faulty hardware in a digital camera. For example, digital camera circuitry is known for having “dead” pixels that cause a pixel to be a constant color (salt/pepper noise), and a photo, perhaps taken at night, can be grainy (Gaussian noise).

In this activity, a corrupted image is loaded in a script in Matlab<sup>®</sup>, and a mean and median is tested on both. For example, in Fig. 3, the photo is corrupted with Gaussian noise. A **mean** of a pixel-window is taken: given  $[x_1, x_2, \dots, x_9]$  are the intensity of the pixels 1 through 9, their mean can be taken



Gaussian "Snowy" Image



After a Mean 3x3 Filter

**Fig. 3.** An example of an image corrupted with Gaussian noise, and the first step to a solution – removal with a mean. The students can vary the block size and view the “filter”-blur vs. noise trade-off.

In the following activity, you will calculate the mean of a set of numbers in a 3-by-3 window and substitute the box in the center of the window with that box. For example, consider the following 3-by-3 window:

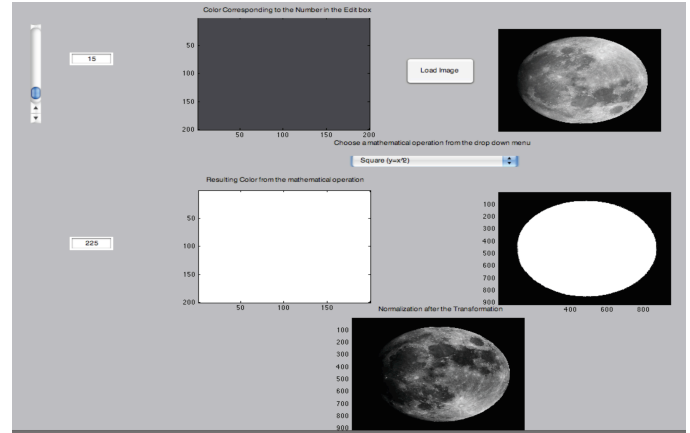
255	128	128
128	New 142	128
128	128	0

First, we calculate the mean of all the numbers in the boxes as follows:  $(255+128+128+128+255+128+128+128+0)/9 = 142$

Then, substitute the value in the box in the center of the window by the mean you just calculated. It just happens to be that the mean you calculated is the same as the value in the center of the box but this isn't always the case. Once you're done, you move this 3-by-3 window to the right by one box and repeat this process. Note that the mean of subsequent 3-by-3 matrices should be calculated using the original values in the boxes. Next, move this window down by a row and repeat the same operation. Finally, move the window to the left and repeat this procedure.

43	55	105	94
102	22	18	40
95	125	155	160
21	105	140	135

**Fig. 4.** In order to understand the mean that was just computed on Fig. 3, students complete an activity before filtering the image. The activity shows a  $3 \times 3$  pixel block example, where students find the mean of the block. They are then encouraged to think about what happens when they shift left by one pixel and recompute the next block. After a few computations, they begin to see the numbers “smoothed” out, and develop an appreciation for the computer’s automated calculations.



**Fig. 5.** Students have the choice of applying a power of 2, exponential, log, and linear operators to the image. They also can select a number and view the corresponding gray shade, and what this shade corresponds to after the transformation. An additional “normalization” step is needed to visualize the final contrast-enhancement.

to replace the center of the window, the  $x_5$  pixel:  $x_5 = \bar{x} = \sum_{i=1}^9 x_i$  where  $\bar{x}$  is the mean of the intensity values. Secondly, students also explore the differences between using a mean and median on salt-and-pepper and Gaussian noise, with the median filter providing superior correction on the salt-and-pepper image. Finally, students also study the trade-off of de-noising vs. blurring the image when increasing the filter’s block size.

This activity has two components: 1) a hand-written activity to compute the mean and median of pixels (Fig. 4) and 2) the graphical interface to control the input image, mean, median, and blocksize of the filter. The idea is that students will compute the filter by hand a few times and begin to see a pattern of how numbers are averaged out using the mean (or how the numbers work out if the median is used). It also gives them a 2-D geometry feel to the problem. After wading through computations for 10-minutes, they now must put the operations to task on the computer. By using the computer to denoise the image, students are then asked to assess which filter cleans up salt-and-pepper noise better and which cleans up Gaussian noise better. Then, students must also write observations about using different block sizes. The hope is that they will learn the effects of each operation and the trade-offs while retaining the mathematical connection.

### 3.3. Linear, Power, and Log Transformations for Image Contrast

In ninth-grade algebra, students learn how to plot equations and begin to work regularly exponents and learn about logarithms and square roots. At that stage, the focus is on having students become systematic in balancing, reducing, and

solving equations. All too often, students do not understand an equation's meaning or interpretation of the corresponding plot when using these mathematical transforms.

To facilitate students' understanding of linear, exponents, and logarithms, students are given a graphical interface, seen in Fig. 5, where they can apply such transforms to images. Transforms include square, square root, exponential, natural logarithm, or linear transformations. They then can use a slider to examine what a particular grayscale color transformed into (e.g. a dark pixel of value 15 would transform into a light pixel of value 225 if squared). A more perplexing issue will be if the pixel value goes higher than 255 with the transformation. A companion activity is given, where students will plot a transformation curve and then use it to transform example pixel values, thereby illustrating the effects that they see on the computer.

Students will be introduced in lecture to the concept of normalization, and the GUI will show a normalized picture. This will lead to the final application of contrasting an image, and how a nonlinear operator can be used for such a task. Many arts students will already be familiar with contrasting from Photoshop<sup>®</sup>. The concept of a logarithm can be related to the fact that the eye senses brightness logarithmically via the Weber-Fechner law [12], and such a concept can be augmented in the lecture. Finally, we will also show students through the lecture how contrast enhancement is integral to medical applications, such as assisting doctors in finding tumors.

### 3.4. Combining Math Operations: Edge Detection

Edge detection can be taught to students at many levels. In calculus, the concept of a gradient and calculating a finite approximation flows quite naturally from the curriculum. In our environment, we target mostly 9<sup>th</sup> and 10<sup>th</sup> grade students, but this concept is not totally lost. The idea of a subtraction is quite simple at these levels, but students are also learning about nonlinear, piecewise functions at this level (e.g. equations 1 and 2). In a lab not shown here, we illustrate a nonlinear operation, gray-scale thresholding, which has the effect of nullifying elements of the image (whitening/blackening portions based on values that fall above/under a particular threshold). To best illustrate the idea of computing with subtraction (or finite-difference) and comparing it to a threshold, an activity was devised (see Fig.6).

Once the students do the computation on paper, they can then appreciate the significance of the computer's automated computation and then test different parameters through a simplified graphical user interface shown in Fig. 7.

To build on the mathematical differential operation they learned with edge-detection, they can then use the edge-detection to apply it to two images, to perform a masking operation. An image mask acts like a stencil to specify where to place a part of another image. We scale two images to

#### ACTIVITY 4: Edge Detection

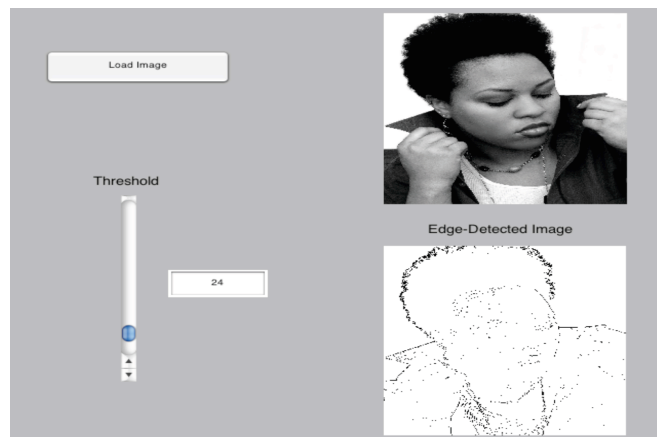
In this activity, you will find the difference between values in each adjacent box and compare it to 20, which is the threshold. If the difference is greater than the threshold, you will color the box to the right black. If not, leave it white. For example, if the values in two adjacent boxes are 50 and 80. The difference between these values is 30 and this is greater than 20. Therefore, you will color the box containing 80 black. Start from the left upper corner of the grid of numbers and compare boxes in the rows only. Note that you need to take the absolute value of the difference which means that you can disregard the sign. For instance, the absolute value of  $50 - 30$  and  $30 - 50$  is the same and is 20.

45	55	105	98	95
102	22	18	40	45
95	100	155	160	162
15	105	110	140	125

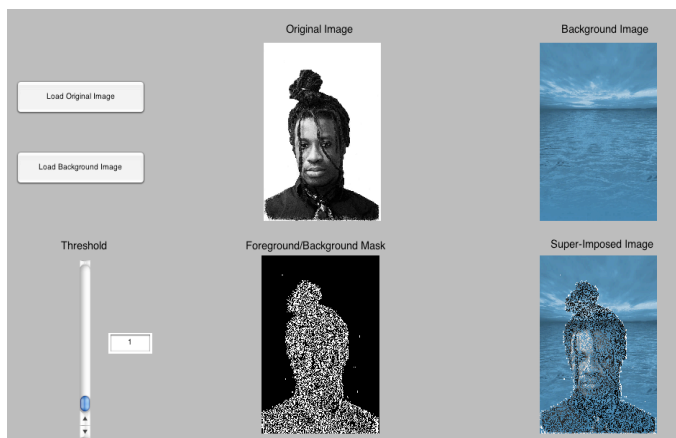
Now, continue with activity 5 where you will the same operation to detect the edges of an image.

**Hint:** There are a total of 6 boxes that need to be colored.

**Fig. 6.** Students take the difference between two pixels and compare it to a threshold of 20, then integrate and repeat to understand a rudimentary edge detection procedure.



**Fig. 7.** The user interface for the edge detection activity.



**Fig. 8.** Once students have understood the mathematical principles behind edge detection, they can apply it to an image to create a superimposed image. In this case, students create a pseudo-ghosting effect.

be the same size. Then using the edge detection function, adjacent pixels that differed more than a threshold were stenciled, whereas those that do not were not placed in the mask. Then using the locations of the binary edge detection mask, those pixels that meet the edge-detection threshold replace the pixels in the second image. This creates an effect of super-imposition and can have varying effects. In Fig. 8, as the students decrease the threshold value, the image of the man fades into the sea, creating a “dissolve in” effect, such as that found in Microsoft Powerpoint®.

#### 4. DISCUSSION OF THE LAB TEST RUNS

In this section, we report on our initial implementations of the laboratories. These were pilot implementations that took place in two after-school “special events,” each lasting approximately 2 hours. Some, but not all, of the participants took part in both labs. Students were recruited to participate by CAPA teachers and were provided with incentives to participate. We worked with a total of 32 CAPA students who were primarily 9<sup>th</sup> grade students and all of whom had focused their studies in one of the CAPA “majors” (creative writing, dance, instrumental, theater, visual arts, and voice). At the beginning of the session, participants completed a pre-survey to gather background information on their experiences and beliefs towards STEM. After the two labs, students completed a post-survey. In addition, in the week following the lab implementation, students took part in focus groups that were designed like open-ended interviews where students could talk about their personal STEM experiences in and out of school and their experiences in the labs.

All of the participants had completed or were currently completing Algebra I and were taking Physical Science. While the students indicated that these courses focused on

“applications,” they did not feel that the applications were relevant to them. Approximately two-thirds of the participants did not like math and science and approximately the same proportion of students felt that math and science were “not hard at all” or “not very hard.” All of the students felt that it was important to be told how to solve problems step-by-step and described “being cut-and-dry” and “having one right way to [solve problems] and one right answer” as the reasons what they liked about math and science (even if they did not like the subjects). While we were not able to document any improvement in science or mathematics knowledge, we were able to capture shifts in students’ beliefs about science and mathematics and the relation to science and mathematics to their interests. When asked in a focus group to describe what they learned in the labs, student responses included:

*“I didn’t know that there was math involved in [that] stuff, and like, I don’t personally like math. But when I looked at it, and saw, like, that digital pictures were all about math and numbers and when I looked at it, I was like, OK, that’s pretty cool.”*

*“I think it was cool that we learned, we learned everything was made of pixels and all the different colors that there are in a picture are made of colored pixels. I mean I knew that, but I didn’t know all the different numbers and all the different ways you could mess with them. It was just like so interesting to learn about like everything behind the picture. Instead of it just being a picture. We learned about we learned that its more than just that. Its numbers and pixels and stuff. We really were able to figure out why.”*

*“Pixels are the small blocks with a particular color number. Pictures have lots of blocks of different colors. 255 is white, 0 is black and there’s all the stuff in between, like lots of grays. Its like that’s how Photoshop tells what color [the pixels are].”*

*“It was neat to try to make colors. Like, we made [yellow] by turning off the green. Or was it the red? Or both?”*

These student comments are not meant to demonstrate that all students had begun to think about digital images as being comprised of many pixels with RGB components. In fact, one student, when asked what a pixel was, responded that it was the number on the outside of my grandmom’s camera.” What these student comments are evidence of, though, is that as a result of participating in the labs, at least a *portion of the students* have begun to think more deeply about the ideas and concepts that lie behind the technology that is part-and-parcel with the digital photography and video, both of which are integral in the creative and performing arts. A final example of such thinking shows the depth of thought that is possible



to exist at the confluence of STEM and the creative and performing arts:

*"I'm not sure I really get the point. Or why it was important to us. I got all the ideas, like getting rid of a black spot that wasn't supposed to be there, but the [computer applications] did all the work for us. But, like, say I had a picture and I wanted to [remove the noise]. I wouldn't be able to do it. It's like pointless because we wouldn't be able to do it."*

We believe that this student is an ideal example of a student who has come to see the complexity of the task and the value of the automated de-noising process. She later notes that *"So all we really needed to know is which one [of the de-noising methods] to choose?"* providing evidence that she has made connections between the DSP content focus, digital editing software and the lab activities.

We are currently planning more robust survey and interview protocols in order to understand some important emergent questions (such as does the involvement and interest depend on the students' choice of major) and to quantify changes in both their understanding of important STEM concepts and their beliefs about the relations between STEM and their creative and performing arts interests. We have begun to devise a one question quiz for the end of each module that will allow the facilitators to focus on what the students are thinking and not just to focus on covering the content. We will also be using these quizzes as part of our overall project assessment.

## 5. CONCLUSIONS AND FUTURE ENHANCEMENTS

As a part of the NSF Discovery K-12 program at Drexel University, we developed several image processing activities during the 2007-2008 school year. The labs illustrate physical light and many mathematical concepts. Some of the math concepts were extended to illustrate how they are used in image-editing applications, such as denoising, contrast enhancement, edge detection, and image-superposition. We have showed through student comments that we are able to stimulate some students interests in math and science careers while engaging their interest in and *applying* the classroom concepts.

The engineers that are designing the labs usually find themselves focusing on activities that convey one or two curricular concepts. Such a narrow focus detracts from the larger picture of connecting students to real-world applications. For next year, we plan to give an everyday demonstration to engage students into the "big picture" before delving into the details of the lab – such as having students use Apple's "Instant Alpha" feature (an application of edge-detection that removes the background of a photo while preserving a primary object) before doing the edge-detection lab. Students

can then get a hands-on experience with an application before they learn about the details and math behind it.

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