

Inquiry-Based Learning Through Image Processing

As in many states, educators in Pennsylvania school districts are strongly encouraged to incorporate science, technology, engineering, and mathematics (STEM) activities and applications into the high school classroom. Incorporating topics on engineering into the high school curriculum poses a challenge for the educator, however, since most science textbooks and teacher resources (for levels prior to college) include little if any engineering content or activities [1]. Therefore, teachers must consult

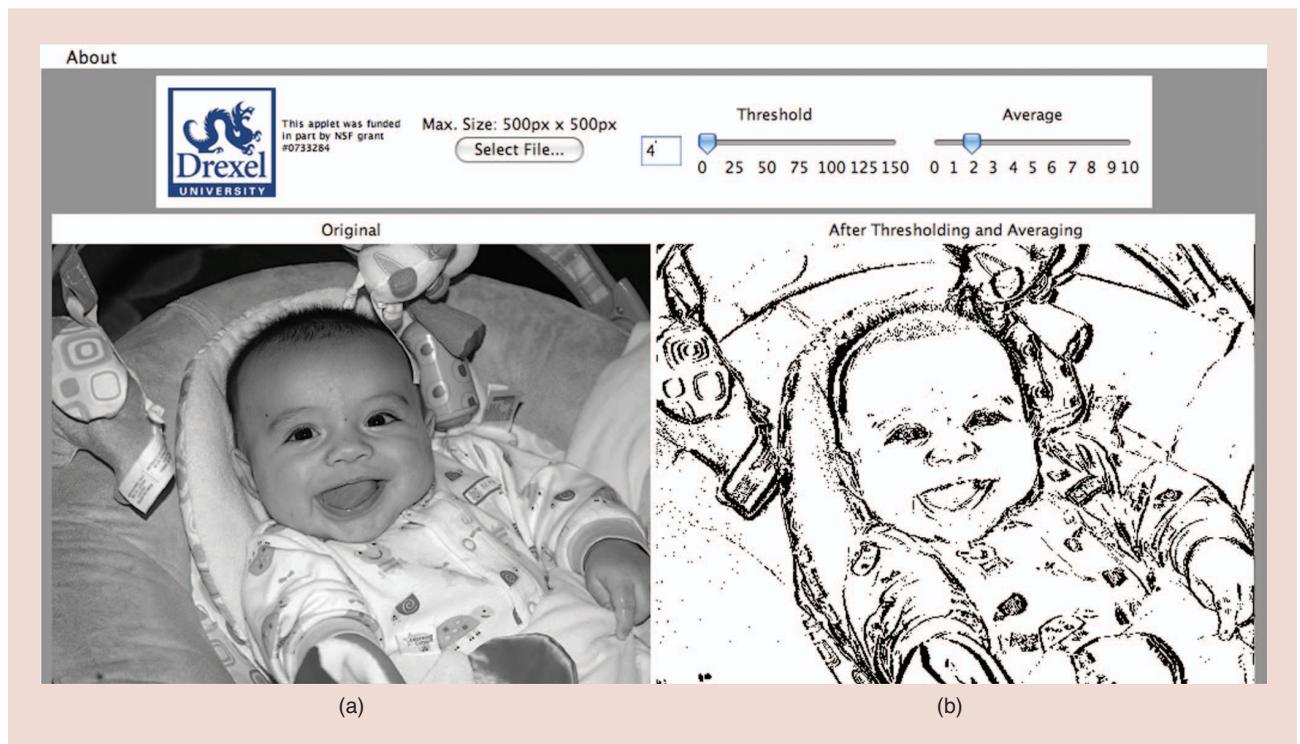
alternative resources if they intend to include engineering concepts in the classroom. With recent educational cuts and standardized testing stress, educators have little time to seek out such resources.

Hands-on activities may well provide the much-needed play (inquiry) that is missing from the U.S. school system [2]. For example, researchers at Oulu University (Finland) have conducted a project to teach microcontrollers in grade school by letting students formulate their own problems to solve [3]. Similarly, as profiled in *ASEE Prism Magazine* [4], schools in Finland attribute their success in engaging students into STEM to well-trained teachers who

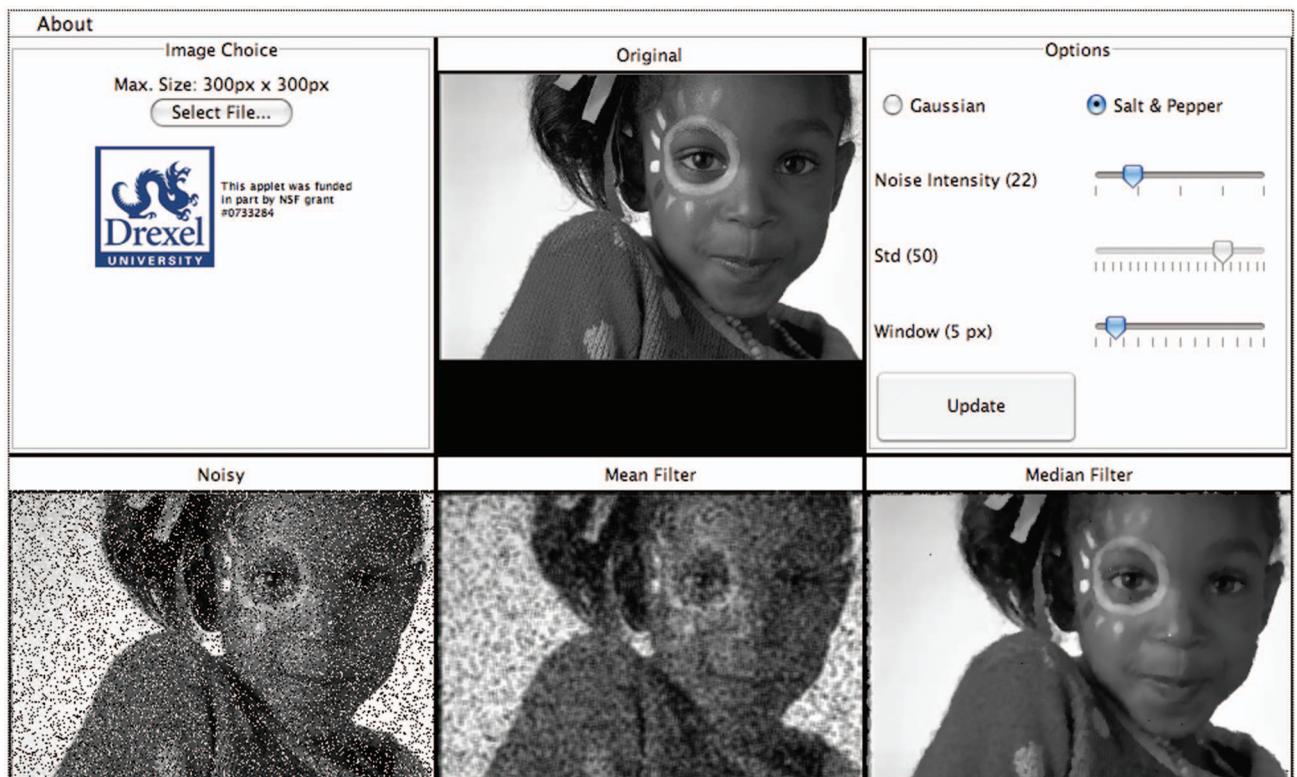
design special hands-on activities as part of their regular teaching activities. The authors [4] note that “One girl, a Boston transplant, says she hates the idea of returning to her American school, where students never did anything in the lab and had more homework.”

The National Council of Teachers of Mathematics (NCTM) standards call for teaching mathematics for understanding where students “actively build new knowledge from experience and prior knowledge.” They call for inquiry-based instruction whereby students are encouraged to investigate legitimate questions and hypothesize about solutions leading to the discussion and evaluation of potential solutions.

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[FIG1] Edge detection applet. In this example, the user specifies that pixels more than five values apart (on a 0–255 luminance scale) in (a) will be marked with black (level = 0) in (b). In this example, the user has also chosen to take an average of two pixels before taking the difference (thus altering the filter parameters). (Image courtesy of Gail Rosen.)



[FIG2] The denoising applet. In this example, the user specifies that the intensity (average number of pixels per 100) that contain salt-and-pepper noise. The user can see that while the mean smooths the noise out, the median filter is much more effective. (Image courtesy of Kodak Eastman Company.)

We argue that digital signal processing (DSP) also provides a great venue to let students inquire and explore. Previous activities, such as the Infinity Project, have made progress in bringing DSP to the high school classroom via textbook and curriculum development [5]–[7]. In this column, we present a variety of activities and related interactive applets that were developed by our project team to allow students explore and manipulate mathematical functions through the context of image processing. We will discuss the ways in which these activities and applets can support and enhance student learning and student beliefs about mathematics and science.

DESCRIPTIONS OF THE IMAGE PROCESSING APPLETS

The culmination of our image processing labs has resulted in four major applets: 1) edge detection, 2) the addition and correction of noise, 3) mathematical transformations, and 4) the concept of

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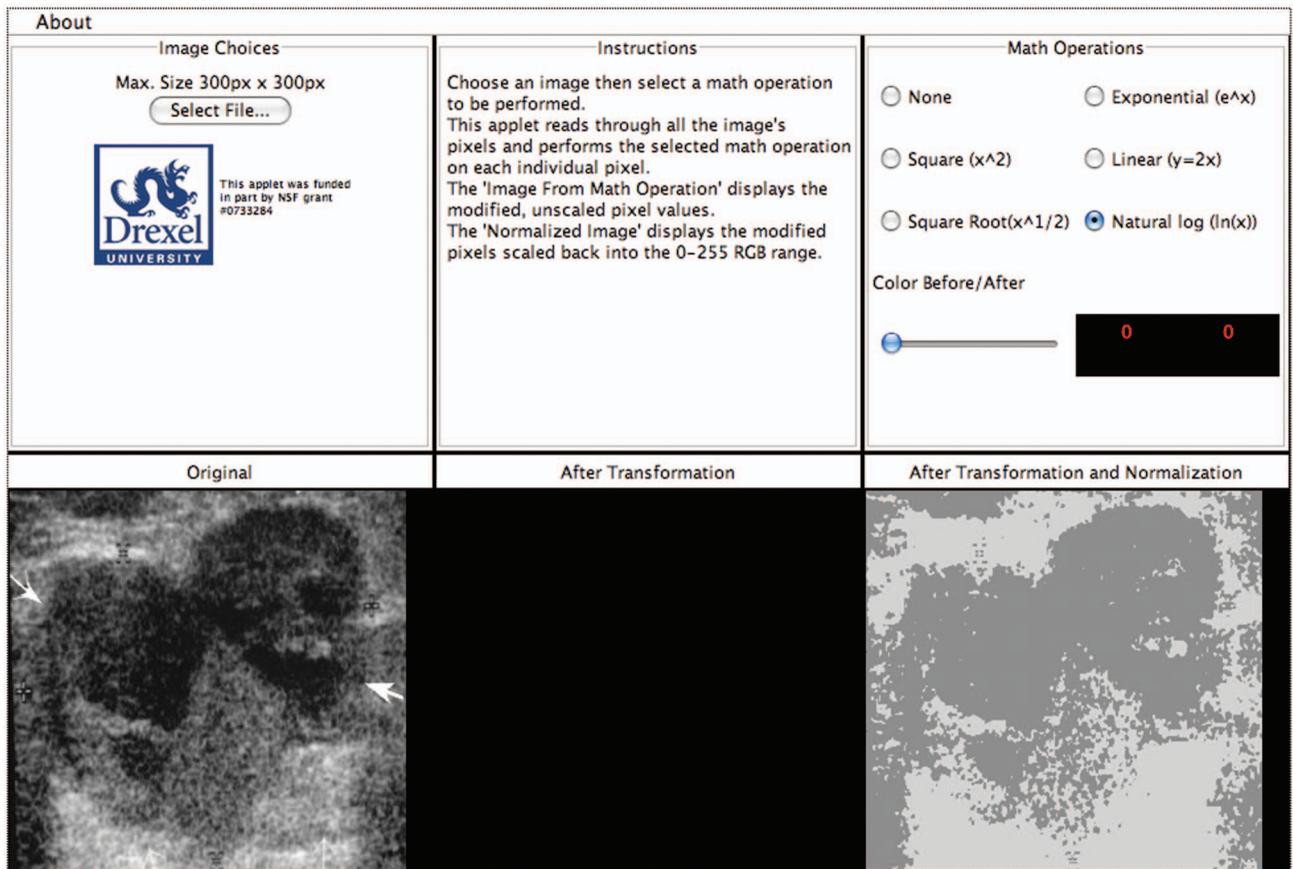
the red, green, and blue (RGB) color channels. Except for 4), all applets operate on black-and-white images [two-dimensional (2-D)] using the luminance scale, thereby eliminating the abstract concept of adding more dimensions to the numeric matrices for the color channels. We felt that working in color-space would complicate the mathematics that we wished to focus on, but we introduce the concept in the RGB tinting applet. For the edge detection and denoising applets that apply one-dimensional (1-D) operations to 2-D images, we conduct the operations first by rows and then by columns, allowing simple 1-D mathematical concepts to be applied in 2-D. To illustrate the row/column operations, we have students manually calculate such

operations on worksheets as preactivities in the classroom.

The first two applets are based on initial labs first conceptualized and implemented in the classroom (with MATLAB code) in 2004 [8]. Through several iterations, they were refined and developed into MATLAB graphical interfaces allowing inquiry. Now, in this column, we are pleased to introduce the cross-platform JAVA applets for use by the public, students, and educators.

EDGE DETECTION

The goal of the edge detection applet is to explore the effect of a first-order difference filter on an image to detect edges. We also let the user explore the addition of coefficients in the difference equation through an average operation that improves performance. As most signal processors know, the $y[n] = x[n] - x[n-1]$ is a first-order difference equation and is a crude high-pass filter. Effectively, we have the students calculate this difference on an activity sheet to



[FIG3] The transformation applet. In this interface, the students can visualize an example of medical image processing and be able to take a natural log transform to delineate cancerous and noncancerous cells. (Figure courtesy of [10].)

understand this operation. They then can adjust the threshold, t , for which $y_{\text{new}}[n] = 0$, if $y[n] > t$, else $y_{\text{new}}[n] = 255$. The threshold is adjusted through an input box and a slider bar. There is also a slider bar called “Average,” which allows the user to average several pixels (e.g., 3 pixels): $y[n] = 1/3 * \{x[n + 2] + x[n + 1] + x[n] - (x[n - 1] + x[n - 2] + x[n - 3])\}$ to compute an averaging of pixels to compare versus the threshold (Figure 1). The averaging operation is a way that the students can learn about lengthening the FIR filter to gain better results via inquiry.

DENOISING (NOISE)

In this applet, the user can explore the effect of noise and filtering to correct the noise on an image. The user can adjust the noise parameters and view the image before and after the addition of the noise, which is of two types: Gaussian or salt and pepper. If Gaussian is selected, a

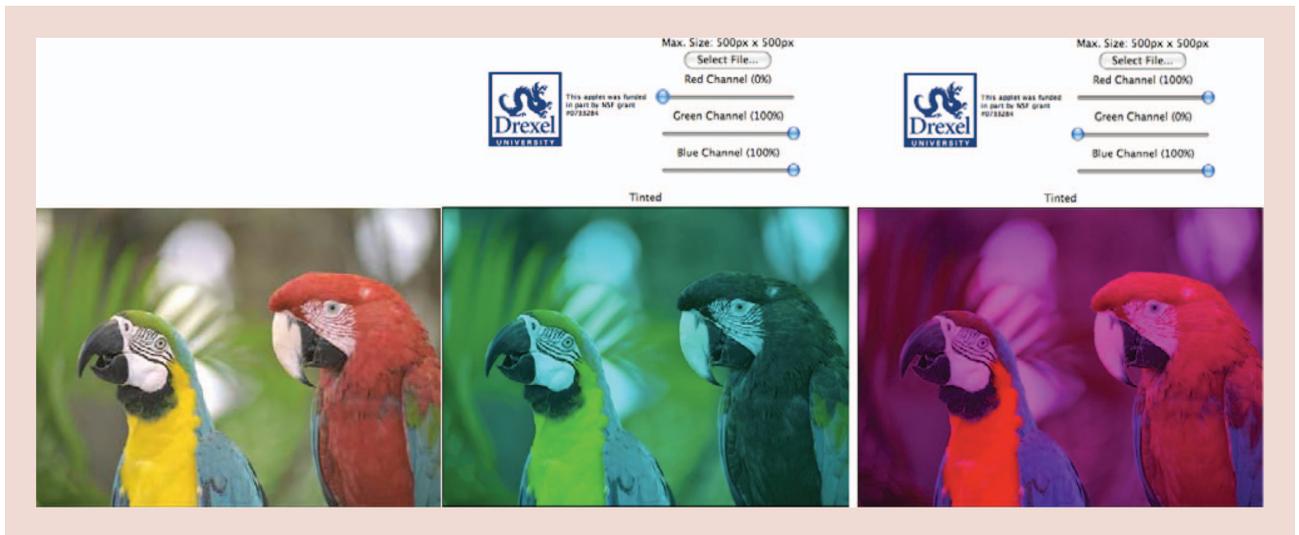
THE GOAL OF THE EDGE DETECTION APPLET IS TO EXPLORE THE EFFECT OF A FIRST-ORDER DIFFERENCE FILTER ON AN IMAGE TO DETECT EDGES.

mean and standard deviation of the Gaussian distribution can be adjusted via slider bars. Therefore, the standard deviation value is the most important value to adjust the Gaussian noise level. If salt and pepper is selected, the number indicates the proportion of pixels that are affected. The user can then specify a window of size N (of $N \times N$ pixels) to filter the image. The original and resulting images for the mean and median filtering are then illustrated (Figure 2). The students can then experiment and observe which filter method works better on Gaussian noise and which works better on salt and pepper noise.

They can also experiment with window size and severity of the noise. We also have a companion activity sheet for the lab, where students hand calculate the mean and median filtering from pixel values to gain an appreciation for the automation of computers and to compare/contrast how the mean/median computations work.

TRANSFORMATION

This applet aims to give a sense of different mathematical transforms and their effect on images. We allow the user to explore the true and displayed (due to the fact that values above 255 are clipped to 255) luminance values before and after a particular transformation through a slider bar. To avoid concealing all the mathematical workings of transformations, we show the raw effect of the transformation and show what the values look like clipped and then after a normalization process



[FIG4] This is a basic applet where students can adjust the amount of red, green, and blue (RGB) in each color channel and observe the effect. (Image courtesy of Kodak Eastman Company.)

in which the numbers are linearly normalized back into the range of 0–255. The users can explore the exponential, square, linear ($y = 2x$), square root, and natural log transforms (Figure 3).

TINTING

The tinting applet allows students to learn about the RGB spectrum on an image in real time (Figure 4). Although the function is available in most graphic-editing software, this allows focused experimentation in the classroom without distraction.

EXAMPLE STUDENT ASSESSMENT

We incorporated a mechanism for real-time feedback during the lab to assess the students' current level of understanding of the fundamental concepts being taught. At three different points during the lab, we pass out note cards (sometimes sheets of paper) to the students and have them answer a question about the material they've just covered in the lab. The questions are designed to elicit short-answer, narrative responses, and student response time is limited to about two minutes. Three note card questions were presented to the students over two 40-min lab sessions. Example questions asked during the lab along

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with the desired response from the students follow.

QUESTION 1: "WHAT HAPPENS WHEN YOU VARY THE THRESHOLD (PIXEL-TO-PIXEL DIFFERENCES) IN THE EDGE DETECTION ALGORITHM?"

EXAMPLE OF THEORETICALLY CORRECT ANSWER (THE RESPONSE SHOULD BE BASED ON THEIR EXPERIMENTATION WITH THE EDGE DETECTION APPLET)

A lower threshold will show more edges than a higher one. As the threshold is lowered, the outline of the person will become more visible. However, spurious edges will begin to appear in the image giving a noisy appearance. Most of the pixel-to-pixel transitions in the image have small differences except around the outline of the object/person. These small differences will not be detected by the algorithm at a high threshold. However, as the threshold is lowered, the algorithm detects edges

throughout the image that are not the true edges, resulting in perceived noise in the image.

QUESTION 2: "HOW DOES THE AVERAGE VALUE EDGE DETECTION ALGORITHM COMPARE WITH THE ORIGINAL ALGORITHM?"

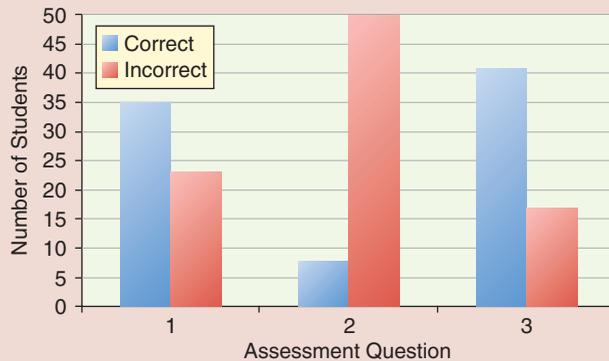
EXAMPLE OF THEORETICALLY CORRECT ANSWER

This algorithm reduces the amount of spurious edges in the image when operating at a low threshold. This is due to the algorithm basing the decision of edge detection on averaging multiple pixels (four or more) rather than using just two as in the previous algorithm. The tradeoff is that we lose resolution on the precise definition of the edge. Also, the edges consist of lines that are much thicker than those previously.

QUESTION 3: "WHAT IS THE PERFORMANCE TRADEOFF WHEN SELECTING A WINDOW SIZE FOR THE DENOISING ALGORITHM?"

EXAMPLE OF THEORETICALLY CORRECT ANSWER

The tradeoffs are resolution, speed, and noise. A small block size will execute quickly but will still leave some noise in the processed image. A large block size



[FIG5] Positive/negative understanding of some of the image processing concepts. The students understood the threshold and block size concept, but the complex algorithm of averaging pixels before calculating the difference was not as well understood.

will remove the noise, but will lower the resolution of the image, causing it to appear blurry and will also take more time to execute, resulting in lag.

RESULTS OF THE STUDENT ASSESSMENT

The image processing labs developed for our program were presented to ninth and tenth grade students in their respective math courses over a two-day period at the Creative and Performing Arts High School in Philadelphia, Pennsylvania (CAPA). A total of 58 students participated in the lab activities: 27 from Algebra and 31 from Honors Geometry. Each class worked 40 min per day on two lab activities. The first day comprised a brief lecture on image processing, two activities focusing on edge detection algorithms, and a follow-up

discussion. The second day began with a student-led discussion, which reviewed the activities completed on day one. The

WHILE THE LABS WERE SUCCESSFUL AT CAPTURING STUDENTS' INTERESTS INTO STEM SUBJECTS AND SUPPORTING STUDENTS' UNDERSTANDINGS OF FUNDAMENTAL DSP CONCEPTS, THERE CONTINUES TO BE ROOM FOR IMPROVEMENT IN LAB DESIGN.

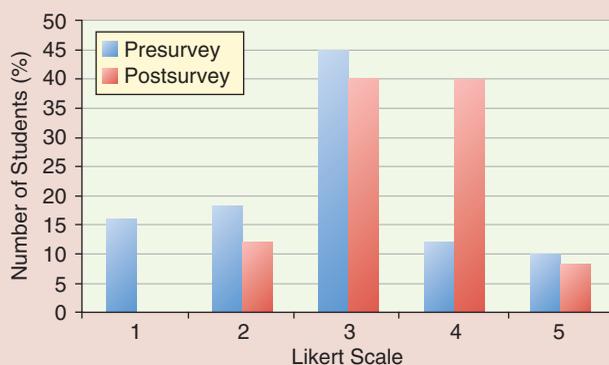
rest of the period focused on two activities based on denoising algorithms as discussed in the methods section.

In our study, all 58 student responses were analyzed by a member of the research team to determine whether the students responded in a way that was conceptually similar to the theoretically correct answers and, if not, the response was coded as incorrect. The grader was the graduate/undergraduate student who designed the question, and the grading was subject to whether the grader believed that the student understood at least one basic concept being asked by the question. Responses were tallied and reported in the bar graph shown in Figure 5, which illustrates that for the edge detection lab, a majority of students understood basic concepts of threshold and block size but struggled more with the complex algorithm of averaging pixels before comparing the difference to the threshold operator.

We also provided pre- and postsurveys to these 58 students at the beginning and end of the school year (after we had been in the classroom six times). For this particular student audience, who often do not identify themselves as mathematically or scientifically oriented, an example survey question captures a shift in students' beliefs about mathematics and science, shown in Figure 6 (more positive shifts in student interests in STEM, feelings of self-efficacy for STEM, and shifts in mathematical beliefs, can be found in [9]). Overall, the surveys and note card questions indicate that while the labs were successful at capturing students' interests into STEM subjects and supporting students' understandings of fundamental DSP concepts, there continues to be room for improvement in lab design.

FURTHER INFORMATION ABOUT OUR PROGRAM AND AVAILABLE RESOURCES

Our research is part of a National Science Foundation (NSF)-funded exploratory project aimed at developing, implementing, and evaluating new multimedia laboratory activities in collaboration with teachers at CAPA. These activities are designed to engage students in the STEM disciplines. In particular, through our collaboration with CAPA, our activities



[FIG6] Pre- and postsurvey results before/after the last year of the program. Students rated this question on a Likert scale: "Compared to your creative and performing arts endeavors, how much would you say you like math and science?"

target artistically gifted students who may have steered away from math and science in favor of more traditionally creative areas (e.g., arts and humanities). Our overall goal was to capture interest in STEM by demonstrating that STEM is a part of the creative arts.

More about our program, including the information packets (describing our lesson plans), activity sheets, and MATLAB user interfaces can be found at http://dk12.ece.drexel.edu/Labs_And_Activities_IP.html. The JAVA interfaces can be found at <http://dk12.ece.drexel.edu/applets.html>.

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OUR OVERALL GOAL WAS TO CAPTURE INTEREST IN STEM BY DEMONSTRATING THAT STEM IS A PART OF THE CREATIVE ARTS.

knowledge and the role of technology in mathematics education.

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DOCTORAL SUPPORT in SIGNAL AND IMAGE PROCESSING, Fall 2012

The Department of Electrical and Computer Engineering (ECE) at The George Washington University (GW) invites applications from individuals interested in pursuing a Ph.D. in Electrical Engineering, for a fully-supported program concentrating in signal and image processing.

The program combines doctoral study at The George Washington University with the applied research effort of Corbin Company's Technical Services Division supporting the U.S. Army's Night Vision and Electronic Sensors Directorate (NVESD) located in Ft. Belvoir, Virginia.

During the doctoral program, the successful candidate will receive base annual compensation commensurate with experience of at least \$45,000, plus tuition and other expenses, with eligibility for full benefits plan (i.e., paid leave and holidays, 401(k), medical and dental coverage). This program's duration is designed for as many as five years. Interested candidates should be available for research beginning in summer 2012 and prior to matriculation in the doctoral program in the fall of 2012.

To be considered for this program, the candidate must:

- (1) have a Master's degree in electrical engineering or a closely-related field before May 31, 2012
- (2) must have cumulative GPA of 3.4 or higher
- (3) meet the doctoral admission requirements of ECE,
- (4) be a U.S. citizen, and must be able to obtain and maintain a Secret security clearance

Applications must be received before 15 Feb 2012 to be considered.

For further information, please contact **Chris Whitty** at Corbin Company for a preliminary application form. Please do not send personal or academic information until requested.

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