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STEM Digital STEM Education Institute

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Proposal Narrative

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1. Project overview

STEM Digital Images in Geoscience Investigations: Teaching Analysis with Light (STEM DIGITAL) is a proposed Strategies ITEST project from the University of Massachusetts Amherst (UMass). It will enable high school and middle school STEM teachers and students to conduct environmental research aided by the analysis of images from digital cameras, scanners, and the Internet.

Image analysis plays a large and expanding role in the workplace, providing excellent diverse career opportunities in technical fields such as medical diagnostics, satellite remote sensing, and national security. Digital cameras are potentially powerful tools for inquiry based curricula, classroom research, and learning about image analysis. They have become ubiquitous as their prices plummet and capabilities improve, making them affordable for classroom use. However, teachers and students mainly use digital images for documentation: creating PowerPoint presentations, handouts, posters, etc. There are good examples in the literature of how to use digital imaging as an investigative tool, but these are seldom seen in classrooms.

STEM DIGITAL will explore how digital image analysis can be applied to environmental quality issues that can readily be introduced into a wide range of K-12 STEM courses. These will engage students and encourage them to think about related careers. The project will develop research agendas that will employ a variety of image analysis tools. The air quality theme will focus on the three components of the atmosphere that primarily affect visible, infrared and ultraviolet light, respectively: particulates and aerosols, carbon dioxide, and ozone. The water quality theme will look at the role of plant biomass on drinking water quality and on global carbon cycling. Arsenic is listed as number one in the US in terms of environmental contaminants that pose a potential threat to human health; research topics will include the identification and mapping of local arsenic contaminated sites and bioremediation possibilities.

The project staff has extensive experience in teacher professional development and curriculum design. It includes PI Morton M. Sternheim (Physics; Director, STEM Education Institute); co-PI Stephen Schneider (Astronomy), Julian Tyson (Associate Dean of Natural Sciences; Chemistry) and David Reckhow (Environmental Engineering). Allan Feldman (Education, University of South Florida(USF)), will provide educational research support. The staff will include secondary teachers and teaching assistants. STEM DIGITAL will use the AnalyzingDigitalImages (ADI) software developed by consultant John Pickle (Pickle, 2009), formerly at the Museum of Science in Boston and now at Concord Academy. It provides free, easy-to-use tools for spatial, temporal, spectral, and intensity measurements, and will be improved and made more portable by rewriting it in Java.

There will be three cohorts of 30 teachers. Secondary teachers typically have over 100 students, so we expect to ultimately reach at least 9000 students each semester. Additional students and teachers will be reached by the dissemination effort. The first two groups will attend one week summer institutes in 2011 and 2012. During each of the following school years, we will continue working online with the teachers on approximately six more projects spread over the fall and spring semesters. These will be a combination of new projects, extensions from summer projects, and data sharing projects. The 2013 institute will be entirely online, with a 6 week summer course. This course will become a permanent part of our self-supporting Science Education Online (SEO) masters program for teachers.

Curriculum materials created by the staff will reflect Pellegrino's "Construct-Centered Design" (CCD) model (Pellegrino, 2008; Krajcik, 2007) in which assessment is an integral part of their design and use. This model will also provide the educational research framework for improving their efficacy. An essential component will be the feedback from five teachers and their students who will serve as "alpha testers" before the first institute as well as input from participating teachers during and after the summer programs. Connections with state and national curriculum standards will be highlighted. We will also discuss related career opportunities ranging from environmental research to regional planning.

Teacher incentives will include stipends, food and housing as needed, and funds for materials. They will receive free "Professional Development Points" needed for continuing licensure, or optional reduced-cost graduate credits. We will encourage applications from teams that include STEM teachers plus computer teachers or coordinators in order to strengthen the impact of the program in the school.

All the curriculum materials and software developed for STEM DIGITAL will be made freely available via the web. Additional dissemination will include articles for science education journals and presentations at regional and national conferences. The evaluation will include a study of the effects on student career interests. It will also compare the efficacy of the face-to-face and online models.

The *intellectual merit* of STEM DIGITAL is that it will enable teachers and their students to use digital images and image analysis software for qualitative and quantitative analysis, engaging students, improving their in-depth understanding of fundamental science and technology, and ultimately increasing their interest in STEM and information technology (IT) careers. It will add to our knowledge of important environmental processes related to the movement of arsenic compounds in the environment and the dissolution of natural organic matter. It will also allow us to compare the efficacy of the in-person and online professional development programs. Its *broader impact* is the demonstration to the educational community that already available computers and digital cameras, along with online data, can easily and effectively serve as hands-on scientific instruments, adding a new dimension to the way STEM subjects are taught.

2. Project Goals and Objectives

Our ultimate goal is to increase middle and high school student interest in and preparation for studying STEM and IT disciplines and careers. STEM-related employment grew over three times faster than the total workforce between 1950 and 2007 (NSF, 2010), and is expected to continue to grow faster in the next decade than the overall workforce (U.S. Department of Labor, 2009). The growth in STEM degrees has not kept pace with the overall demand, and the gap has been filled by foreign-born scientists and engineers. The U.S. is expected to face a serious shortage of skilled workers in STEM fields over the next twenty years (NAS, 2007; ACT, 2006). At the same time, studies have shown that fewer than half of high school graduates are adequately prepared for first-year college math and science (Greene, 2005). We seek to increase the participation in these fields, particularly by women and under represented minorities, through project driven learning and by utilization of emerging digital technology and visualization tools, as recommended by several recent reports (Johnson, 2009; Sheppard, 2008). We will enable teachers to provide opportunities for students to apply an in-depth understanding of fundamental science, gained in part through STEM DIGITAL applications, to develop possible solutions to complex environmental issues. Providing students with such opportunities has been noted as a key component for advancing engineering education in K-12 classrooms (Brophy, 2008). Specific objectives include:

1. Developing effective teacher workshops (both week-long and online follow-on activities) that excite and engage teachers in the active process of learning how to use STEM DIGITAL environmental quality curriculum materials and ADI software. This includes preparing teachers to use digital cameras, scanners, and online resources with computer software to collect and interpret scientifically useful data that support education and research efforts.
2. Developing an online STEM DIGITAL graduate course that will be a permanent, self-sustaining UMass Continuing Education Science Education Online offering for teachers.
3. Creating and revising a variety of environmental quality applications that can be used with middle school and high school students in a broad range of science disciplines
4. Broadening the participation of underrepresented minority and low income groups by targeted teacher recruitment.
5. Creating and making available an open-source JAVA based version of AdvancedDigitgalImaging with increased functionality for multiple platforms.
6. Conduct a strong evaluation program, including measures of the growth of student interest in STEM courses and careers.
7. Expanding the program impact by a vigorous program of dissemination of the STEM DIGITAL materials and findings.

3. Explanation of principles that guided the project design

In this section we first explore the role of digital image analysis in the workplace and in schools, and then describe our rationale and curriculum development process.

Digital Imaging in the Workplace

Despite the cutbacks in Internet and related IT employment, the Bureau of Labor Statistics projects that strong growth in IT jobs will continue in the next decade. Within the broad area of IT, digital image analysis plays an increasingly large role in the workplace. An upcoming Optical Society of America conference is devoted entirely to Digital Image Processing and Analysis (DIPA, 2010). The conference announcement notes that "*the number of images that are sensed, stored and displayed digitally continues to increase dramatically in virtually every imaging system from video endoscopes and digital phones to digital cameras to remote-sensing satellites and astronomical telescopes. A major important feature of digital images is that they lend themselves to various processing techniques that can be used to enhance the visual appearance, to extract important information automatically, to format for data storage and transmission and to optimize the image data for display.*" An example of this dramatic increase in the number of images is the report that the US military is awash in images from Predator spy drones flying over Afghanistan and Iraq, and that this problem will intensify as more drones are added and they are upgraded from one camera per drone to 10 and eventually to possibly as many as 65 (NY Times, 2010). Automated systems that can reliably extract important information do not yet exist.

Digital images are used in nearly every form of IT in which data are spatially organized and integrated. They are important in many areas of science, engineering, technology, economics, and environmental studies. A wide range of medical career paths require an understanding of images ranging from MRI scans and x-rays of skeletal structures to neuro-images that reveal the structure, function, and pharmacology of the brain. Visible and infrared satellite images are used to map land cover change in the study of climate change, and thermal images of a building can be used to maximize its energy efficiency. Geographic Information Systems (GIS) is a multibillion-dollar industry, but there are impending shortages of skilled GIS professionals (NAS, 2006). Careers using digital images, creating new digital imaging technologies, or inventing new digital image analysis capabilities will be a key to the 21st century economy.

Digital Imaging in the Schools

Digital photography and image analysis can play a major role in strengthening inquiry based learning experiences (Leonard, 2004). However, there is little research that has been done on how photographs, digital or otherwise, can serve as resources for inquiry in the science classroom. Instead, what we see are studies on how students comprehend diagrams (e.g., Lowe, 1996), the use of photography as a tool for learning science (e.g., Meyn, 2008; Rivet, 2004), and as a way to document student learning (e.g., Hoisington, 2002). The most common use of photographs in science education is as illustrations in textbooks (Roth, 1999), which when carefully constructed can enhance learning (Carney, 2002). Slykhuis, (2005) has shown through eye-tracking technology that students attend more to highly relevant photographs than those that have little context. In addition, little research has been done on their pedagogical role except for that done by Pozzer and Roth in which they categorized the functions of photographs used in high school biology textbooks (Pozzer, 2003, 2004); and categorized the functions of a teacher's gestures when photographs are presented in lessons (Pozzer, 2005).

Digital cameras have become ubiquitous as their prices plummet and capabilities improve, making them affordable classroom tools for a variety of applications with varying degrees of sophistication. Digital images are used in various ways:

- At the simplest level, images obtained with digital cameras or from the web are widely used for documentation purposes as students and teachers create handouts, reports, posters, web sites, and PowerPoint presentations. Photoshop or other software may sometimes be used to enhance or modify the photos, but there is no attempt to extract scientific data from the images.

- At the most advanced level, teachers and students have been introduced to GIS software and learned how to do sophisticated analyses. Unfortunately, GIS has a steep learning curve. With a program like Microsoft Word, you can learn how to create a basic document in an hour or less. However, GIS is much more complicated and not very intuitive, even its simpler forms, and it takes a large effort and time commitment to gain even minimal proficiency. Novices cannot do much after a one or two day introduction, as we learned after offering such workshops. Several ITEST GIS programs have provided the needed extensive training. For example, *Eyes in the Sky: Applied Information Technology Project*, gives teachers a distance learning course followed by a two week face-to-face workshop, and an implementation phase (Eyes, 2009). *Coastlines* offers 25 webinars and a two week summer workshop (Coastlines, 2009). Universities typically list GIS courses at the advanced undergraduate and graduate levels, and Penn State offers an MS in GIS. Not many teachers or schools are able to provide students the extended instruction needed for learning GIS, although it can be done. GIS is also limited: it focuses on one fairly narrow set of applications, and does not fit into the curriculum of most STEM courses.
- There is a middle ground where digital image analysis is used as an investigative tool with the aid of appropriate software that requires a much shorter time commitment and is more intuitive for teachers with minimal technical proficiency; this is the focus of STEM DIGITAL. As digital cameras get better and cheaper, and as computers become commonly available in school science labs, this becomes an attractive way to improve teaching and learning in a wide variety of courses while interesting students in related careers. An early and still evolving physics application is tracking the motion of falling objects (e.g., Sternheim, 1992; Pinto, 1995; Terzella, 2008; Kulp, 2008), basketballs (Abisdris, 2007)), and bagels (Singh, 2000). Another example of *space-time measurements*, from our nanotechnology institutes, is the study of the diffusion of food dyes in gelatin, modeling the diffusion of nanomedicines in human tissues (Dun, 2009). There are also experiments measuring the diffusion of dyes in air and in water (Keith, 2003), laminar burning velocities (Uske, 2004), the fermentation of yeast (Leonard, 2003), and the growth of tree rings (Mims, 2005). The *color* of transmitted light has been used to measure yeast growth rates (Bealer, 1998) and the effectiveness of water filtration media (Hargis, 2001). In chemistry labs, colorimetric analysis can replace a spectrophotometer (Soldat, 2009), serve as a tool in thin-layer chromatography (Hess, 2007), study absorption (Kohl, 2006) and adsorption (Shishkin, 2004), and measure starch (Mathews, 2006), iron (Kompany-Zareh, 2002; Suzuki, 2006), and protein (Stickle, 2002).With the aid of the free ImageJ program (ImageJ, 2010), we have measured the *intensity* of reflected light to determine the albedo of surfaces in discussions of climate change in our International Polar Year program (Sternheim, 2009). The Measuring Vegetative Health project (MVH, 2008) used the ADI software extensively to study an area's environmental health.

STEM DIGITAL rationale and curriculum development

The above examples show that almost any STEM course can benefit from the introduction of digital image analysis. However, despite the widespread access to digital cameras and computers, these engaging applications are seldom seen in classrooms. The basic problem is that most teachers need training and support if they are to progress in their use of computers beyond the level of word processing and PowerPoint presentations. The availability of free, easy-to-use digital image analysis software is not sufficient by itself, even though the learning curve is much less challenging than it is for GIS.

As we noted above, there is little research on the use of digital photography in classrooms. However, there have been many studies on the barriers to the incorporation of computers and other information technology (IT) into teachers' daily practice. One barrier is that teachers are uncertain about how to use computers for instructional purposes and lack confidence in their own ability to develop ways to do so (Adelman, 2002; Jacobsen, 2002). As a result they do not feel prepared to integrate technology into their instruction (Zucker, 2000). As Becker noted, "Differences in computer use among subject-matter teachers are often dependent upon their own belief and confidence in using the technology themselves" (2001). Because of teachers' lack of expertise, confidence, and knowledge, they need a significant amount of time to figure out how they can best incorporate IT into their practice. Lack of time to do this is a second barrier to the incorporation of IT into teachers' practice (Adelman, 2002; Cuban, 2001; Zucker, 2000). The STEM DIGITAL summer institute and academic year program will help teachers to develop the necessary computer skills and confidence, enabling them to be both effective and efficient in classroom implementations, and in a much shorter time frame than required for GIS.

Cuban (2001) identified three other barriers that teachers face as they attempt to use IT in their classrooms. One is the structuring of schools into 'cellular classroom arrangements' that impede the sharing of equipment and expertise among teachers. STEM DIGITAL will provide funds for teaching resources, and the online component will facilitate this expertise sharing. A second is the focus on preparing students for high-stakes examinations, which leads teachers to believe that there is no time for innovations or that they are too risky. Accordingly, the project's environmental quality applications are designed to fit into many existing curricula, potentially improving student interest and learning. Finally, even the best technology fails at times. Because teaching is very much like live television, there is little room for technical failure. If teachers feel that the new technology is not reliable, then they will stop using it (Cuban, 2001). This should not be a major concern since modern digital cameras and computers are very reliable, and the ADI software is very robust as well as easy to learn and to use.

With a September 2010 project starting date, we will have an entire school year to develop summer institute materials. One task will be the conversion of the ADI software to Java, producing an improved, platform-independent program; a graduate assistant will do this conversion and also support the online program. The UMass faculty, with the aid of the school faculty and another TA, will develop specific curriculum materials for the three environmental quality threads: air quality, water quality and arsenic contamination. Five experienced high school and middle school teachers and their students will test these materials. We will use student assessment data and feedback from these "alpha testers" to make improvements. Further improvements will be made based on input from the two cycles of summer institute participants both during the institutes and the school year. This is discussed further below.

The curriculum materials will be closely tied to state (MA Dept of Ed, 2009) and national curriculum standards (NAS, 1996). The development process will be based on the "Construct-Centered Design" (CCD) model (Pellegrino, 2008; Krajcik, 2007). This model will also provide the educational research framework for improving their efficacy. Steps of the CCD model include:

1. Select the big idea that brings a focus to the activity.
2. Identify the grade level of the students.
3. Unpack the big idea (construct), expanding concepts and identifying components.
4. Create a claim that describes the types of understandings expected of the students.
5. Specify what evidence you will accept that a student has the desired knowledge.
6. Design particular tasks, questions, or assessment tasks.
7. Design particular learning activities.
8. Review assessment tasks.
9. Review learning tasks.

The CCD model is compatible with assessment strategies described in the National Science Education Standards (NAS, 1996, page 76): "*In the vision described by the National Science Education Standards, assessment is a primary feedback mechanism. For example, assessment data provide students with feedback on how well they are meeting the expectations of their teachers and parents, teachers with feedback on how well their students are learning, districts with feedback on the effectiveness of their teachers and programs, and policy makers with feedback on how well policies are working.*"

Pre- and post- assessments will be administered. They will provide feedback to students and their teachers and will be designed to determine how well an activity advances the students'

- understanding of fundamental scientific principles and processes associated with environmental science
- ability to collect and analyze digital image data that builds an understanding of a given problem
- interest in pursuing STEM and IT coursework and careers.

The assessments will indicate if the activity needs to be restructured and/or if ancillary materials need to be developed. These assessments plus the STEM DIGITAL program evaluation will provide feedback to participating schools and to the broader educational community that indicates the extent to which the project has met its goals.

4. Detailed Project Description

We begin this section with detailed descriptions of the three environmental research themes: Air Quality, Water Quality, and Arsenic. We then describe the features of the ADI image analysis program and the online course. The concluding discussion covers project management and the timeline.

Air Quality Theme (Stephen Schneider)
The way sunlight is scattered and the slight colorations it produces are often our first hint of air quality problems. Scattered light may indicate natural hazes, particulates, or chemical pollutants. Less obvious but of planet-wide importance is how certain gases in our atmosphere affect light at wavelengths we cannot see: global warming caused by the absorption of infrared light, ozone depletion which leads to the transmission of solar ultraviolet radiation. We breathe the atmosphere and it shields the Earth.

We will study the properties of air using modern technologies as well as simple hands-on experiments that will help to elucidate the properties of air and its interactions with light. We will study the air in the immediate environment of our schools and communities, and we will access satellite and ground-based monitoring data to expand these studies to the global view. Understanding how air absorbs and transmits light at different wavelengths is fundamental to the processes that take place in the atmosphere as well as to the technologies that let us measure atmospheric composition. The air theme will focus on three components of the atmosphere that primarily affect visible, infrared and ultraviolet light.

Most digital camera light sensors have a spectral response ranging from 330 nm (near UV) to 1200 nm (near IR). To make images of visible light (400-700 nm), filters are placed over the sensor inside the camera. When these filters are removed, a digital camera becomes an inexpensive, broad spectrum light detector, measuring millions of light intensities instantly - and the measurements are in a digital form readily processed on a computer. To analyze the reflectance, transmission, or emission of light over a narrow range of wavelengths, filters placed over the camera lens and the narrow bandwidth of light emitting diodes (LEDs) may be used to control the wavelengths of light reaching the camera's light sensor. Using a light spectrometer, the best signals may be identified, and then the camera, filters, and LED lighting will be designed to maximize the signal that can be analyzed efficiently with the camera.

<u>Particulates and Aerosols</u>. When we see air with a hazy, brownish hue, it's generally a good indication of smog. Using Google Earth to measure distances and the visibility of remote landmarks can help to compare different days (NASA Earth Observatory project). Students will make these observations more quantitative by photographing distant landmarks and analyzing the changes in color and transparency digitally. These digital results will be compared to US EPA AIRNow monitor values to develop a better understanding of the relative contributions of different particulates and gases (such as nitrous oxides) to scattering and coloration of the air (AIRNow, 2010). Photographs of the sky over a wide range of angles from the Sun can reveal additional properties of particulates in the atmosphere (Mims, 2009, 2010).

The atmospheric path length changes how much atmosphere the light passes through, thereby altering the degree of scattering by pollutants. The image analysis software allows for absolute and relative color change along lines drawn on the image. An additional feature, an angle tool, will be added which will allow one to measure the radial distribution of absolute and color change around the sun. Finally, the intensity and orientation of polarized light in the sky is enhanced by a greater concentration of air pollution. Using a polarized filter and a digital camera in movie mode, the orientation and intensity of polarization may be recorded, and unpacking the frames from the movie and using them in the image analysis software will allow the spectral range of polarization to be measured and related to the air quality.

Carbon Dioxide Some gases are clear at visible wavelengths, but they block infrared light. One of the most important is carbon dioxide because of its role in trapping heat in the Earth's atmosphere. Carbon dioxide is also often used to estimate indoor air quality, since its presence provides a measure of how quickly the carbon dioxide we breathe out is replaced by fresh air.

Electronic monitors based on infrared absorption can provide accurate readings of CO_2 levels, but they are expensive. For a few dollars, a class can mix up a pH indicator such as BTB (Bromothymol Blue) and bubble air samples through the liquid placed in small vials. The resulting color change provides a quick indication of relative CO_2 levels, and using a digital camera, it is possible to make more quantitative measures of color change. Photographing the reaction and the color standards in one image should minimize the influence of light quality.

Clear containers, as simple as 2-liter soda bottles, provide an opportunity to demonstrate greenhouse warming more directly. Student teams can build "greenhouse chambers" and place them side-by-side over a heat source to compare the absorbing effects of different gases and other variables that might affect global warming. Students will relate their data to satellite measurements of CO_2 from NASA's Atmospheric Infrared Sounder (AIRS, 2010) and the Japanese Ibuki satellite (GOSAT, 2010).

Ozone plays important roles both as a caustic chemical pollutant and as a shield against ultraviolet light coming from the Sun. "Bad" ozone at ground level is often associated with nitrous oxides, which contribute to its chemical production. Ground level ozone can be monitored with electronic monitors (which measure the ultraviolet absorption) or with chemical test strips (Figure 2). These test strips are often difficult to read, so here again analysis of digital images will help to quantify the results. Measurements with these strips often show enhanced levels around roads, bus stops and even some electronic equipment, allowing students to explore sources in their immediate environment. Students will also measure the total ozone column overhead using an ultraviolet absorption monitor. This data can be compared to ozone measurements from NASA's Total Ozone Mapping Spectrometer (TOMS, 2009) satellite.

Figure 1 Measuring ozone with test strips

Middle and high school science curricula routinely address the properties of air, and also cover pollution impacts as well as atmospheric changes over time. This theme can easily be incorporated into earth science units as well as high school physics, environmental science and chemistry.

Water Quality Theme (David Reckhow)

Fresh water is extremely important. We use it for drinking, preparing food and bathing, as well as in agriculture, industry and recreation. The presence of contaminants can severely impede its use and lead to serious health problems. Even the most pristine water contains some salts and natural organic compounds. The amount of naturally-occurring organic compounds in water, sometimes referred to as natural organic matter (NOM), varies widely from one location to another and from season to season (Thurman, 1985). In addition, global warming may indirectly result in higher levels of NOM in many types of fresh waters (Hongve, 2004).

Terrestrial vegetation is a major source of dissolved organic carbon in surface waters and ground waters. The quantity and quality of this material is highly dependent on the nature of the vegetation, including species, growth state and dominant type of plant tissue. Our research at UMass on this subject has focused on the generation of dissolved natural organic matter (NOM) from dead vegetation, the subsequent biodegradation of that NOM and its properties including elemental composition, spectral characteristics, mass flux and reactions with chemicals used in drinking water treatment. Not only do these have implications with regard to global carbon cycling, but they also affect the quality of our drinking water. Some types of NOM may even react with disinfectants normally added to drinking water, producing halogenated byproducts that have been associated with elevated levels of bladder cancer.

We will work with teachers and students to develop research programs in NOM generation and reactivity. They will collect plant tissues (leaves, stems, buds, roots, etc) from a range of native species. They will then create simulated classroom vernal pools, allowing them to observe the natural leaching process. This can be done with inexpensive fish tanks and de-chlorinated tap water. The students will regularly collect samples of the water for testing and record their observations. Direct measurement of the water color can be done from the simulated vernal pool (i.e., the fish tank) by visual inspection and with digital cameras. Data from the cameras can be used to estimate absorbance at several wavelengths.

Absorbance over a range of wavelengths has been shown to provide valuable quantitative and qualitative information on aquatic NOM. In addition, a few simple water treatment tests can be run in the classroom, including coagulation tests (by addition of alum), and chlorine demand tests (by addition of dilute bleach and titration of the residual bleach after a short reaction time). This will allow the students to make conclusions on the impact of various types of plant matter on drinking water treatment and finished water quality. Additional samples could be collected for subsequent testing at UMass, such as analysis of total organic carbon, and analysis of trihalomethanes from chlorination. Ultimately, the students will generate a database on the leaching potential of various species of plants and plant parts. They will learn about one important step in the global carbon cycle. They would also learn about drinking water treatment and the role of natural organic matter in water quality and human health.

Teachers will be able to incorporate investigations such as these into biology, earth science and chemistry units as well as into environmental science.

Digital image analysis processes that were described for the other STEM DIGITAL threads will be employed to analyze the color: absolute and relative color intensities of the water compared to those measured against a color scale. The spectral range photographed ranges from near UV to near IR, with the bandwidth being limited using filters and lighting from LEDs. In addition, the change in color for changing depth of water should increase the precision of the color analysis.

Arsenic Theme (Julian Tyson)

Arsenic compounds have been, and still are, used as pesticides, herbicides and fungicides. We spray solutions of them on roadsides, orchards, and lawns; we impregnated construction timbers with a solution of chromium, copper and arsenic. This kind of wood has been phased out for domestic purposes, such as decks and docks, but a considerable legacy remains. It is not known to what extent this material is responsible for environmental contamination. We have also inherited many old chemical manufacturing sites, as arsenic compounds were often discarded along with other wastes. Arsenic is number one in the US in terms of environment contaminants that pose the most significant potential threat to human health. A major issue is how to clean up (or remediate) arsenic-contaminated sites.

Naturally occurring arsenic compounds (mostly inorganic arsenite and arsenate) can get into drinking water. The arsenic contamination of ground water (from minerals) is a serious issue. It is not only a problem in the US, but it is a major problem in Bangladesh and West Bengal, India where millions of people are drinking highly contaminated water and are showing signs of chronic arsenic poisoning. The relevant issues are (a) how can we remove arsenic compounds from contaminated water and (b) how can we test in poor communities whether the water is safe. We are now starting to see arsenic contamination in food, especially rice, as the contaminated ground water is being used to irrigate agricultural land.

There are other issues: in the US arsenic-containing drugs are fed to chickens; arsenic was a component of some embalming fluids and is now leaching out of cemeteries; and arsenic may be a contaminant of deicing salts. Arsenic compounds (especially lead arsenate) were used as pesticides in the production of fruit (including local orchards) and as desiccants in cotton production, and are currently still used as herbicides. Concerns are being expressed over the residues of arsenic compounds that were used as chemical warfare agents. The reality is that most communities in the US contain substantial amounts of arsenic, distributed as a variety of compounds that are potential hazards either as contaminants of locally produced foods and beverages, or by inadvertent direct ingestion especially by children.

Although the relevant concentrations are low, typically at single-digit part-per-billion (ppb) values, it is possible to detect some arsenic compounds at these levels by simple colorimetric procedures. Several companies market “field test kits” designed to measure arsenate or arsenite in water down to 10 ppb. These are usually based on the “Gutzeit reaction” – the reaction of the arsenic species with zinc and acid to form arsine and hydrogen. The volatile arsine escapes into the headspace of the reaction vessel and reacts with mercuric bromide impregnated into a paper strip, forming a yellow-brown colored product. The intensity of the color is compared with those on a preprinted strip for a range of known concentrations. The “molybdenum blue” reaction can, under the appropriate conditions, give a visible color in solution for 10 ppb of arsenic as arsenate (Matsunaga, 2005). Neither of these methods is reliable, and attempts to improve the analytical performance have been the basis of a number of undergraduate research projects and one RET project in the Tyson group. One promising line of investigation has been to work with digital images of the strips or solutions obtained with either digital cameras or flat bed scanners. We have shown that it is possible to relate the R, G and B values obtained by averaging those of a number of pixels in an image of the indicator strip to the arsenic concentration in solution by a monotonic decreasing function. The analysis of these images will be done using the same approach as with the BTB measurements in the Air Quality Theme (Dhar, 2004; Rahman, 2004, 2006; Soldat, 2009).

The arsenic project offers two intertwined themes for students and teacher researchers that models the way that measurement science underpins advances in other sciences, namely (1) the development of more reliable measurement tools, (2) and the application of the measurement tools to the study of, in this case, the biogeochemistry of arsenic compounds.

Method development projects not only include the study of how to obtain and analyze digital images of colored spots and solutions, but also the study of how to improve the tests themselves and how to adapt tests that were originally designed for the analysis of water to the analysis of other relevant materials such as soil, plants, foods, and pressure-treated wood. In addition to the two chemistries mentioned above (the Gutzeit reaction and the molybdenum blue reaction), there are other reactions that could be investigated, including at least two based on changes in the optical properties of nanoparticles (Kallure, 2009; Morita, 2006). Reaction rate is a crucial parameter, and a study of the reaction kinetics is an important aspect of any method development project.

Environmental projects would include the identification and mapping of arsenic-containing timber structures in the local community (e.g. decks, docks, fence posts, telegraph poles, play structures, sign posts and traffic noise reduction barriers), and the investigation of the extent of leaching of arsenic from such structures. The application of arsenical pesticides and herbicide means that golf courses and old orchard sites are contaminated. The transfer from soil, or water, to plants forms the basis of a number of studies of the possible contamination of food crops and of strategies for phytoremediation (Stamps, 2004). A large number of materials, both bio-organic and inorganic, are potential arsenic adsorbers that might be candidates for the construction of point of use filters to remediate drinking water (Figure 2).. The role of micro-organisms in chemical transformations is also a relevant environmental research area. Soil bacteria are implicated in the volatilization of arsenic, bacteria in the shallow aquifer in Bangladesh are responsible for the dissolution of the iron oxide + “arsenic” coating on the gravel, and bacterial production of arsines is a possible contributor to sudden infant death syndrome (so-called “cot-death”).

This theme will incorporate well into existing lessons for teachers of chemistry at both the middle and high school level.

Figure 2. Arsenic removal from contaminated water by steel wool

AnalyzingDigitalImages (John Pickle)

Analyzing Digital Analysis (ADI) is the core program in a free package of software tools and tutorials developed by John Pickle when he was at the Museum of Science in Boston and PI for the Measuring Vegetative Health project (MVH, 2008). It supports spatial, temporal, spectral, and intensity measurements and comes in Mac and Windows versions. It is easy to use, and most importantly, easy to learn; one can quickly get started with just a short introduction. It has been used recently by the CDC with digital cameras to quickly measure insecticide residues using colorimetric analysis (Green, 2009). The associated materials provide insight into the nature of light: the electromagnetic spectrum, mixing of colors vs. pigments, and the effects of filters. The summer institute will start with this study of light.

Digital images contain a variety of data, so to harness the data for student-designed research, an image analysis program must be able to access the range of data types in an intuitively integrating way. The ADI software was designed for students to measure the spatial relationships and spectral values of objects in the image, and the spectral data within spatial patterns in digital images. And when digital images are taken in a time sequence, it can also measure the temporal change of spatial and spectral patterns recorded in the images. As was illustrated in the description of the analysis methods for the atmospheric particles, ozone, dissolved carbon dioxide, organic carbon and arsenic concentrations, we need to study the color or change in color in different locations of digital images or within a time series of digital images, and ADI is ideal for these tasks.

STEM DIGITAL will rewrite the ADI program in JAVA to make it platform independent and faster. One new feature will automate the comparison of two photos of the same scene, so that if there is no change in the image, it will be black and white; changes will appear in green or magenta, and the program will allow calculating the percentage change. There will be new options for outputting histograms of colors along lines and saving this and related information. An angle tool will be added that calculates an angle from horizon or between two lines drawn on the image; this will be useful for the air quality studies. Measurements of total intensity independent of color will be added. Additional features may be added based on the feedback from teachers and students.

The summer institute will also cover related computer topics, including using Excel to import, analyze and graph data, and image file formats, sizes, and compression. STEM DIGITAL will encourage teams of teachers to apply for participation that include both a science teacher and a technology/ computer/media teacher or coordinator to provide for richer connections at their schools.

Online Course Development and Dissemination

One of our goals is to develop a hands-on, online course that will capture the best elements of the program, and which will encourage collaboration between teachers during the academic year. We have experience in developing discipline-specific online courses for science teachers with major hands-on components through the Science Education Online (SEO) program at UMass, and we will use this experience to inform the development of a new course, "Re-imaging the Environment." We will use the public domain *Moodle* courseware to develop the course, hosting it on the UMassK12 servers; we have been using this program for several years to support online nutrition courses. This will permit easy dissemination of the course at the end of the program and provide opportunities for the teacher participants to use the same software in a blended mode with their own classes.

This online courseware will be made an integral part of the summer course, and its use will continue after the workshop to help us extend projects and add new projects for teachers during the academic year. The courseware will become a site for the teachers to maintain online journals, pose questions, and submit reports during the summer. This will help them to gain familiarity and comfort with the online interface, which will remove one of the hurdles to learning the programs when they are busy teaching. In our experience with past summer workshops, in which relatively little use of courseware occurred during the workshop, teachers struggled to remain active online during the school year. Yet, with our SEO courses, teachers remain highly-engaged in one or two courses even while teaching full time. What the SEO teachers report is that the online courses provide a place where ideas can be shared and developed for almost immediate use in the classroom.

One of the features of the SEO classes is that they all use digital cameras to share pictures of projects and results. This makes the contact between the teachers and the course instructors much more personal than purely text-based courses. These images help the instructors and classmates to diagnose problems with experiments, and it alleviates many of the concerns about genuine participation in a distance-learning setting. The new course developed during this project will take this an important step further—the color and intensity values within the shared images will become a significant source of the data used for scientific analysis. Furthermore, even inexpensive digital cameras now record a wealth of data in *EXIF* headers that can assist us in interpreting the images.

Online Course Development Timeline. As explained above, before the first summer institute, the staff will develop the protocols for the experiments that will be carried out both during the summer and in the following academic year. This will be aided by TAs, who will try out each project and prepare the initial materials for the *Moodle* lesson environment. These will then be further tested in classrooms by five middle and high school teachers. Feedback from them and the student assessments will guide revisions. In the summer institute we will develop the content presentations of the course and test out the projects with a cohort of 30 science teachers. This will also provide an opportunity to record the presentations (using Camtasia, for example) and to film short videos to illustrate steps involved in each of the projects. The workshop participants will collaborate in the development of the presentation materials, both through their comments and by providing examples and additions.

During the school year, we will continue working with the teacher cohort on approximately six more projects spread over the fall and spring semesters. These will be a combination of new projects, extensions from summer projects, and data sharing projects. The timing and content of these projects will be largely decided by the teachers during the summer workshop to match their curriculum needs.

For example, we might carry out a project to compare arsenic levels around playground equipment at our teachers' schools, and perhaps the majority would find this most useful for their curriculum in October. Classes could collect data and teachers upload data and pictures. Comparisons of results between schools will perhaps suggest other areas to test or different procedures to follow. Some data will likely inspire further investigation—perhaps older pressure treated wood equipment has been replaced, but residual arsenic remains. The broader world of comparisons between schools will provide a positive context for non-detections of arsenic—which might otherwise seem "disappointing" to students. Similarly, ground-level ozone or water quality measurements could be coordinated. Each such project would have deadlines for uploading data and for comparing and reporting results. The teachers and their students will also use the web to explore digital image analysis career opportunities.

The second summer institute and school-year follow-up would be similar to the first, refining projects based on the teachers' experiences. By the third summer, we will design and run the institute fully online over a standard six-week summer session. Teacher-participants will be invited to a two-day follow-up to do a thorough post-course analysis and evaluation to refine the course. We will then continue the course as a regular online offering for science teachers through our SEO program.

Project Management and Timeline

Table I below summarizes the STEM DIGITAL timeline. The leadership team will include the four UMass faculty (PI Sternheim, co-PI Schneider, Tyson, and Reckhow), two retired teachers, and the project manager. They will meet weekly in year one and biweekly in later years to monitor the curriculum development, ADI update, *Moodle* development, etc., as discussed above. The evaluators and TA's will sometimes attend, as will consultants Pickle (ADI) and Feldman (educational research) via the web.

A key task of the team will be to define the summer and academic year agendas for the participating teachers. This agenda will balance the environmental research components, the computer technology, career information, and pedagogic issues including student assessments.

	Year 1				Year 2				Year 3			
Activity	F	W	S	S	F	W	S	S	F	W	S	S
Leadership meets regularly	x	x	x		x	x	x		x	x	x	
ADI software upgrade planning	x											
ADI software upgrade		x	x	x	x	x	x	x				
Moodle courseware, web site development		x	x	x	x	x	x	x	x	x	x	
Curriculum materials development	x	x	x	x	x	x	x	x				
Curriculum alpha testing		x	x		x	x	x					
Curriculum materials revision		x	x	x	x	x	x	x	x	x	x	
Recruit teachers		x	x			x	x			x	x	
In person summer institutes				x				x				
Moodle activities, summer 1 participants				x	x	x	x					
Moodle activities, summer 2 participants								x	x	x	x	
6 week online summer institute												x
2 day optional recall, online participants												x
Dissemination: conferences, papers, web					x	x	x	x	x	x	x	x

Table I. STEM DIGITAL timeline. The evaluation schedule is discussed in the evaluation section.

Participant recruiting will focus on schools in the Northeast with large minority and low income enrollments, although we will accept applications from anywhere in the country. Teacher incentives will include stipends, food and housing as needed, and funds for materials; details are in the Budget Narrative. They will receive free “Professional Development Points” needed for continuing licensure, or optional reduced-cost graduate credits. We will give preference to teams including middle or high school STEM and computer teachers or coordinators. We have extensive email lists of district science coordinators and administrators, and a much larger list of STEM teachers. Publicizing programs via these lists and various web sites has produced a strong applicant pool for recent summer institutes. We will also distribute flyers at local and regional STEM education events.

5. Qualifications of key personnel who will be coordinating the project

STEM DIGITAL will have a very experienced leadership team and support staff. PI Morton M. Sternheim is the founder and director of the STEM Education Institute. He has over 20 years of experience in creating and managing programs dedicated to improving science education and implementing the use of educational technology. Co-PI Stephen Schneider has also long been in a leader in teacher professional development, including the development of the Science Education Online program. Faculty participant Julian Tyson has guided student research on environmental arsenic contamination at several age levels including middle school students in a GK12 project (NSF/STEM Connections) and in afterschool clubs (NSF/STEM RAYS), as well as with college freshmen, seniors, and graduate students. Faculty participant David Reckhow has conducted extensive outreach activities, including short courses on water quality issues for the public. John Pickle, who is currently teaching high school physics, astronomy, and meteorology at Concord Academy, created the original ADI program and many of the supplementary tutorials while he was at the Museum of Science in Boston. Allan Feldman, now at USF and formerly at UMass, played a key role in several STEM Ed projects; he will provide educational research support and advice on assessment. Rob Snyder, a retired chemistry, physics, and earth science teacher, is an expert on standards and curriculum development; Holly Hargraves is a retired English teacher, and facilitates interdisciplinary activities. Middle school science teacher Jennifer Welborn has used the ADI program to enable her students to conduct their own environmental research. Project Manager Marie Silver has extensive experience in environmental education, professional development, and project management. The alpha test group who will first test the curriculum materials with their students includes Welborn, Pickle, and three other Concord Academy teachers.

6. Anticipated Results

Anticipated results include

- A package of tested and improved environmental research curriculum materials based on digital image analysis that can be used in classrooms to engage and interest students in STEM and IT courses and careers. These materials will be freely available on the web.
- An updated AnalyzingDigitalImages software package, freely available as compiled and source code versions.
- Summer institutes and academic year online extensions for two cohorts of 30 teachers each, and a summer online course for 30 teachers.
- An online course for teachers that will be permanently available at moderate cost.
- A direct impact on an average of 100 students per teacher for 90 teachers, or 9000 per semester.
- A demonstration that digital image analysis can effectively be used in a range of STEM classrooms with commonly available resources.
- An effective dissemination program that will encourage others to explore digital image analysis in STEM classrooms

7. Evaluation plan

The evaluation will be performed by SageFox Consulting Group, led by Alan Peterfreund and Andrew Habana Hafner. They are the evaluators for many NSF-funded projects with higher education institutions nation-wide, including a number of on-going teacher professional development and pipeline projects in STEM fields, such as the STEM Ed Institute's IPY and STEM RAYS; see Peterfreund's vitae for a list. The program evaluation will concentrate both on providing formative feedback to the project team, helping them improve the offered activities, and on examining summative data to determine the extent to which the project objectives have been met.

Table II below shows the objectives of the project and the evaluation activities targeting each one. Teachers participating in the alpha testing of the middle and high school curriculum will be asked to participate in **surveys prior to and after their participation** in order to gain feedback on the pilot curriculum's strengths and weaknesses, the challenges of using curricula and integration with core curricula and standards. Student participants in the alpha testing of curricula will take **pre- and post-tests** to measure the affects of the curricula on their knowledge of the content.

Teachers from Cohorts 1-3 will be asked to complete a **series of three surveys**, one prior to their summer training (the pre-survey), one after the training (the post-survey), and one at the end of the school year (the follow-up survey). In the first survey, they will be asked to provide their expectations for the program and reasons for participating. In the second survey, they will reflect on the training, and in the third they will reflect on the overall experience of the program. Each of these three surveys will include questions related to teachers' own understandings of IT/digital imagery analysis, which will offer insight on impacts over the course of their participation in the program. The third survey will also ask teachers about their implementation of new instructional strategies through classroom activities that affect their overall approach to teaching key scientific methods and concepts. Another important aspect of the third survey will be asking the teachers about their experience with project sharing through the on-line platform introduced during the summer institute.

Project Objective	Evaluation Activity
Stimulate interest among students in the pursuit of science courses and careers.	Student pre/post surveys
Increase students' understanding of IT/digital imagery	Student baseline/pre/post surveys
Increase students' knowledge of science content.	Student baseline/pre/post content tests
Increase teacher understanding of IT/digital imagery	Teacher pre-/follow-up surveys Teacher focus groups
Improve the ability of teachers to use IT/digital imagery in core curriculum	Teacher pre-/follow-up surveys Teacher focus groups
Assess implications for increasing the participation of under-represented minorities in the sciences.	Teacher-gathered demographic information Follow-up surveys
Development of on-line graduate course	Teacher pre-/follow up survey Teacher focus groups
Disseminate the findings of the evaluation program to researchers, practitioners, and policy makers.	Reports Assistance with papers and presentations

Table II. Evaluation activities

Teachers will also be asked to participate in **focus groups** during the summer institutes that will help contextualize and broaden the responses given on the surveys. These will explore the teachers' perceptions of how the program has improved their ability to engage students in science learning through learning experiences with IT/digital imagery tools. They will also probe teachers' own sense of increased knowledge of IT/digital imagery and its applications to the classroom. Focus groups with Cohort 3 teachers in particular will ask those teachers about their experience with the on-line graduate course experience as compared to a face-to-face model.

The student experience will be evaluated through **pre- and post-tests of content knowledge**, used in comparison with a **baseline group** for each teacher. At the time of applying for the ITEST program, in the spring prior to attending the summer institute, teachers will be asked to administer a baseline test of content knowledge to their students. During the next school year, after participation in the summer institute, teachers will administer a pre-test and post-test of content knowledge to their students at the beginning and end of the year. Students will also be asked to complete **surveys** at the same time as the content tests. These surveys will examine their understanding of IT/digital imagery and their interest in pursuing further science coursework or career paths.

Analysis of the data from these sources will examine the short-term impact on students and teachers with implications for long-term impacts of on-line platforms for curriculum. Longer term impacts can also be analyzed through future analysis of the frequency and efficacy of the on-line graduate course to be developed as a result of the project. The evaluation team will also be active in participating in team meetings, reporting findings, and aiding in the dissemination of these findings via papers and conference presentations.

8. **Dissemination plan**

The STEM DIGITAL web site will make available all the project curriculum materials. It will also contain the PowerPoint presentations and Camtasia recordings of the audio, plus short video clips. Most materials will be in the form of Word or PowerPoint files, not pdf's, so that teachers will be able to adapt and modify them to suit their needs. The ADI software will be made available in compiled versions for multiple platforms and as source code.

Articles on selected curriculum materials will be submitted to science education periodicals, such as NSTA's *The Science Teacher* and the *Journal of Chemical Education*. There will be presentations at regional and national science teacher conferences. The budget will include funds to support travel to these conferences by the participants and the teachers. Teachers will also be encouraged to do workshops in their schools and districts. The results of the evaluation on the impact of classroom use of digital image analysis in general and on student interest in STEM and IT courses and careers will be written up and submitted to science education research journals and conferences.

9. Sustainability

Teachers who participate in our institutes or who are inspired by district or conference workshops will be able to continue using digital imaging with the cameras and computers they have; the research activities require minimal ongoing outlays for materials. The STEM DIGITAL staff will continue to offer guidance as needed. We will also offer the online graduate course "Re-imaging the Environment" as part of the UMass Science Education Online program. The SEO courses were developed with an NSF grant, and are now self sustaining with the aid of relatively low cost tuition fees. Similarly, STEM Ed servers host a self-supporting food safety course developed with FDA funds and offered by our Nutrition Department. These courses offer the anytime, anywhere advantages of online education, and will be available to teachers who in many cases would not be able to attend in-person courses.

10. Summary of results from prior support

The UMass STEM Ed Institute has its origins in teacher professional development programs begun in 1986 by PI Sternheim. Three current NSF programs program have included digital imaging applications; feedback from the teachers from these activities has provided much of the impetus for this proposal. Franklin County STEM Research Academies for Young Scientists (STEMRAYS, #0639687, $800,000, 2006-10), offers after school science clubs; some are using ADI software (Feldman, 2008). IPY STEM Polar Connections (#0732945, $600,000, 2007-10) is a curriculum development and teacher professional development project which makes use of remote sensing data and the digital camera albedo measurements cited above (Sternheim, 2009). STEM Ed is a partner in the NSF funded (DMI-0531171) UMass Center for Hierarchical Manufacturing, offering teacher workshops on nanotechnology; its digital camera gelatin diffusion experiment models tissue absorption of nanomedicines (Dun, 2009). The NSF/GK12 STEM Connections project (#0139272, $1,500,000, 2002-2006) connected urban middle schools with UMass graduate students and professors engaged in environmental research programs (Kisiel, 2003; Sternheim, 2002, 2003). It featured student research on ozone led by co-PI Schneider and on arsenic contamination led by Tyson, who was the PI. Also, a recently completed NASA funded program, STEM Earth Central, included Geographic Information System (GIS) and ADI software (Yuretich, 2008). Schneider was also co-PI of the Science Education Online program (#0243536, 2002-228, $1,200,000) which created an online MEd program of teacher professional development courses. The program was designed for teachers who cannot easily travel to a university for professional development. SEO has led to the development of 14 on-line science content courses for middle school teachers, which span all of the sciences, and 36 teachers have already completed their master's degrees at UMass through this program.