BIOMETRIC TECHNOLOGY PROGRAM TO PROMOTE STEM EDUCATION FOR THE K-12 ENVIRONMENT

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Abstract *— This paper describes an innovative inquiry based mathematics and science K-12 program using biometric technology. The purpose of the lesson was to use research experiences with fingerprint recognition to create a series of activities that allowed students to explore how computers, algorithms, and fingerprint sensors are used to identify people. The underlying goals of the activities were to show how science and math are symbiotic, expose K-12 students to new technologies they would not typically have access to, and discuss STEM careers relating to computers, biometrics, and forensic science. The paper discusses the background of the GK-12 program at Purdue University, the preparation needed to prepare researchers to integrate their research in the classroom, and the activities performed in the K-12 environment. These activities, which included used the mathematical topics of Cartesian coordinates and Pythagorean Theorem to illustrate how biometric technologies, primarily fingerprint recognition, work. Lastly, results of the program are discussed.*

Index Terms — biometrics, education, inquiry, outreach, K-12, STEM

INTRODUCTION

There is a well-recognized national need to inspire more interest in science and mathematics among K-12 students. Without increasing the pipeline of students from the K-12 system in to colleges and universities, the nation will not be able to meet future needs for innovative and well-trained professionals in scientific and technical fields. When young students are excited by science and math as a result of experiences in school or informal education settings, they are more likely to pursue classes that prepare them for success in undergraduate and graduate programs in any of the Science, Technology, Engineering, and Mathematics (STEM) fields. Thus there has been increasing interest in research and to develop programs designed to enhance teacher preparation and classroom support for the type of experiences and content themes that inspire students to view STEM fields as an exciting option for their futures. As such programs are developed and assessed, it is important to disseminate the results of such initiatives so that those with similar goals can consider how to adopt or adapt the successful elements of other programs in to their own efforts to enhance K-12 STEM education and inspire students' interest in science and math.

BACKGROUND OF THE GK-12 PROGRAM

The National Science Foundation's program to support Graduate Teaching Fellows in K-12 Education (GK-12) aims to improve graduate students' communication, teaching, collaboration, and team building skills through professional training, interactions with faculty, and work with K-12 teachers and students. By working with K-12 teachers to integrate their knowledge and research in to efforts to enhance science and math teaching in schools, the graduate fellows also have the opportunity to build and sustain partnerships with schools and teachers, and to enrich learning and increase motivation for K-12 students. The graduate fellows also provide a range of role models for the students they work with, and talk with the students about the diverse and exciting careers that can be pursued by those who are interested in science and math.

Purdue University's GK-12 program, the Indiana Interdisciplinary GK-12 [1], brings together teams of Ph.D. students from across the STEM disciplines to work with teams of middle school science and math teachers. Each team consists of two teachers in a school working with two Ph.D. students for one academic year. The teams focus on enhancing the use of inquiry-based approaches to teaching in the science and math curriculum. They develop modified versions of existing lesson plans used previously by the teachers, as well as entirely new inquiry-based activities that meet all of the appropriate state and school standards and learning outcomes. In particular, each Ph.D. student is encouraged to develop one major multi-day lesson that makes use of their own Ph.D. research subject. This lesson is implemented in the classes that the fellow works with, and in many cases is then used in other classrooms as well as in subsequent years.

To prepare GK-12 fellows and teachers to work in teams to modify and create inquiry-based science lessons, the fellows first participate in a week-long class focusing on learning theories and pedagogy. The fellows and teachers then work together in a week-long workshop focused on inquiry-based learning for middle school science and math. In this workshop the participants learn the fundamentals of inquiry (how to create learning experiences based on the 5E

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model: engage, explore, explain, extend, evaluate [2]), and explore inquiry-based learning by taking on the roles of both students and teachers. The fellows and teachers then plan and develop inquiry-based lessons with the assistance of a GK-12 staff member, a former middle school science teacher who is currently completing his doctoral work in Education on science inquiry.

This paper describes one of the many inquiry programs developed by Purdue GK-12 fellows. In this particular case the senior author, a GK-12 graduate fellow at the time the program was developed, was pursuing research in biometrics at the same time that he was working as a GK-12 fellow in a middle school math classroom. As a result of the GK-12 program and the time he spent working with middle school math teachers and students, he sought out ways to develop an engaging and challenging program of activities that integrated his research with the goals of meeting Indiana math (science) standards and learning outcomes while also inspiring interest and enthusiasm in the middle school students he worked with.

OVERVIEW OF BIOMETRICS

The notion of utilizing personal information, characteristics, or human physiology for identification purposes has been used throughout human history, dating back to ancient civilizations using things such as demographic information, behavioral characteristics, anatomical measurements, tattoos, or personal artifacts [3,4]. Today, biometrics is defined as a set of emerging technologies that can automatically recognize individuals based on behavioral and physiological characteristics [5]. Biometric technologies are used in various applications; law enforcement, cellular telephones, ATMs, time and attendance, and accessing a building, to name a few. Typically, biometric technologies are discussed as belonging to one of two different types, behavioral and biological. Behavioral biometrics include signature and voice recognition; where as biological or physiological biometrics include face, fingerprints, hand geometry, and iris recognition. Some modalities overlap these two categories, as they are functions of both behavioral and biological characteristics; for example, voice, face, and signature have components that are dependent upon each other.

MOTIVATION FOR USING BIOMETRICS

Biometric technologies are ideal for teaching STEM to young learners for at least four reasons. First, the field of biometrics is emerging and the technologies are cutting edge and continually improving, so there is a "wow" factor for students. Second, students may have seen different biometric modalities on television and in the movies, and can relate to the technologies in some form. Third, the field of biometrics is a blending of the STEM disciplines, which makes it easy to explore many areas when educating young children. Lastly, these technologies involve some component of the STEM disciplines, thus various careers opportunities can be discussed to show young learners what they can pursue when they have a strong foundation in STEM.

The importance of using biometrics to teach STEM disciplines is to bridge biological sciences, technology and engineering concepts, and mathematics with new technologies. The benefit of educating K-12 students with new technologies, such as biometrics does the following:

- exposes students to a new disciplines and careers that they may not know exist,
- clear up misconceptions from previous exposure and experiences, such as on television,
- allow students to interact with the technologies, and
- allow students to learn how the technologies work using appropriate STEM principles and concepts that are relevant to the grade level standards.

PROGRAM ADAPTATION AND IMPLEMENTATION IN THE MIDDLE SCHOOL CLASSROOM

As discussed earlier in the paper, there are multiple biometric technologies that exist. So why did we choose fingerprint recognition? Fingerprint recognition was chosen for for three reasons. First, it is the most widely used biometric technology with nearly 60% of the market [6]. Secondly, students have likely seen, heard, or experienced something with fingerprints, whether on television, in a movie, or personal experience. Lastly, the fingerprint sensor and software required for the lesson were cost effective for the school to purchase, increasing the chance for others to adopt this program.

The purpose of this lesson was to use the fellow's research experiences with fingerprint recognition to create a lesson/experiment that would allow students to explore how computer algorithms identify individuals based on fingerprint features. The lesson was also intended to:

- Show how science and math are symbiotic.
- Expose students to new technologies.
- Simulate how computer algorithms process fingerprints.
- Use Pythagorean Theorem and Cartesian coordinates to locate minutiae on fingerprints and find the distance between points.
- Introduce classification schemes and create a classification scheme for fingerprints using understood concepts.
- Introduce students to various careers involving STEM, problem solving, and teamwork, for example engineerss, computer scientists, crime scene investigators, and laboratory technicians.

FINGERPRINT RECOGNITION LESSON DESIGN

The fingerprint recognition lesson was designed with a constructivist approach, specifically using the 5E Instructional Model. Constructivism follows the assumption that knowledge is not transmitted, but rather constructed from experience, with learning occurring from personal interpretations of the constructed knowledge [7]. Building upon the constructivist approach, the Biological Sciences Curriculum Study (BSCS) developed the 5E Model which is based on Atkin and Karplus's learning cycle, and includes five phases of instruction: engagement, exploration, explanation, elaboration, and evaluation [2]. The lesson was developed in this fashion to create interest and curiosity about biometrics (*engage*), encourage students to work together without direct instruction from the fellow or teacher (*explore*), enable students to explain difficult concepts and definitions in their own words (*explain*), enable transferability of knowledge by having students apply what they have learned in biometrics to a new situation (*elaborate*), and measure the effectiveness (*evaluation*).

The final lesson consisted of seven 50 minute class periods that involved time in both the math and science classrooms. The complete lesson plan can be found on the Purdue University GK-12 website [1]. The involvement of both classrooms was important to further illustrate to students the relationship of math and science. The five lesson objectives based on Indiana mathematics and science standards were:

- Define the Pythagorean Theorem as $a^2 + b^2 = c^2$ on right triangles.
- Understand the hypotenuse (c) is the shortest distance between two points.
- Apply the Pythagorean theorem to find the shortest distance between two minutiae points on a fingerprint or other objects on a coordinate plane using cartesian coordinates.
- Describe and develop a classification scheme for fingerprints or other objects.
- Discuss how fingerprint classification systems (algorithms) work and/or how law enforcement identifies people based on fingerprints.

In addition to the aforementioned objectives based on standards, the lesson also required students to express their solutions clearly and logically using the appropriate mathematical terms and notation. Since the lesson required students to use their own words to describe the classification scheme, evidence could be found in both verbal and symbolic work. The fingerprint classification solution students created involved graphs, thus we were able to use graphing to estimate solutions and check the estimates with analytic approaches. Involving the use of graphs and calculations enabled students to perform calculations and check the validity of the results in the context of the problem. Lastly, students were challenged with analyzing a large problem. Thus, students had to identify relevant from irrelevant information, identify missing information, sequencing and prioritizing information, and observing patterns.

The remaining subsections are dedicated to describing the lesson by the phase of the 5E Model: engaging, exploring, explaining, elaborating, and evaluating.

Phase 1: Engaging the Students

The lesson began by attempting to stir interest and excitement about what they would be doing over the next seven days. A video clip from the popular U.S. television series *CSI*: *Crime Scene Investigation* was used to get the attention of students illustrating fingerprints and a crime scene investigation. Following this, questions were asked to elicit responses about what they just saw in the video clip, which were based on students' experiences, such as: has anyone ever watched CSI, seen the movie Bourne Identity, or Mission Impossible? Has anyone heard of the FBI or want to be a police officer, work for the FBI? After discussion, we asked students if anyone heard of a crime scene investigator, criminalist, or a forensic scientist? Next a video was shown that gave an overview of forensic science and a job description for a crime scene investigators. A discussion of what investigators try to collect at a crime scene then occurred. The whole purpose of this was to lead discussion to fingerprints as a source of evidence and identification.

Part 2: Exploring Fingerprints

To further explore fingerprints, students were asked to think of words that described what they saw on the overhead projector (Figure 1) in their science notebooks. The following guiding questions were given to aid student thinking: Is there anything you see that is unique? Are there unique things that happen in the lines? Do you see any patterns, shapes, etc…? Some of the more common student descriptions included: rainbow, bulls-eye, square, maze, coiled, dark, circular, swirl, wave, tornado, start and stops, splits, dots. The purpose of this exploration was to have students examine a fingerprint to break down a large data source into smaller components, with the goal of moving discussion to minutiae points, which were the small points of interest on fingerprints that computer algorithms use for identification.

FIGURE. 1
FINGERPRINT VIEWED ON OVERHEAD PROJECTOR DURING EXPLORE PHASE.

Part 3: Explaining the "Minutiae" of Fingerprints

Following the exploration phase, the class then assembled to share the responses as a group. The purpose of this exercise was to begin formulating a classification scheme that the students could develop and use to identify fingerprints. Although no response was wrong, the teacher facilitated the discussion to lead students to the five fingerprint classification patterns (Figure 2) and basic fingerprint features: minutiae points, cores, and deltas (Figure 3). After all student responses were given and written on the board, the actual names of the classification patterns and minutiae points were given and recorded in student notebooks.

FIGURE. 2
THE FIVE COMMON FINGERPRINT CLASSES [8].

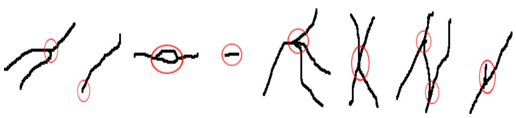

FIGURE. 3
MINUTIAE POINTS (FROM LEFT TO RIGHT): BIFURCATION, RIDGE ENDING, ENCLOSURE, ISLAND, TRIFURCATION, CROSSOVER, BRIDGE, AND HOOK [8].

Next, the fingerprint in Figure 1 was superimposed on graph paper and given to each student. Based on the information students had learned thus far, they were asked to find the core of the fingerprint and label it using Cartesian Coordinates. To illustrate the fact that Cartesian Coordinates are actually used in the "real world", we introduced the ISO/IEC Fingerprint Minutiae Data standard [9], which explicitly discusses coordinate systems (Figure 4). Next, the teacher asked the students to locate minutiae point H (random minutiae point), which was drawn on the overhead. Next, we asked the students to write down in their notebooks how they would find the length of line segment OH without using a ruler or counting the squares of the graph paper. Discussion then took place from student responses, which led to using the Pythagorean Theorem as the algorithm the students would use to compute the distance each minutiae point was from the core of the fingerprint.

FIGURE. 4
ISO/IEC FINGERPRINT MINUTIAE DATA STANDARD SHOWING USE OF CARTESIAN COORDINATES [9].

After the Pythagorean Theorem classification algorithm was understood by the group, each student was tasked to locate five minutiae points on the fingerprint. Once they successfully located the minutiae, they created the right triangles for each minutiae point identified (Figure 5). After labeling all the triangles, the students transferred the triangles and coordinate points to a worksheet to perform the computations (Figure 6). During the time the students were working independently, we prepared for the next day's activity, which was to use a fingerprint sensor to collect each student's fingerprint so they could map the minutiae of their own fingerprint (Figure 7). While we fingerprinted each student, we also displayed the results on the overhead projector, which the students enjoyed. This was quickly modified to be a class participation activity, asking students to classify the pattern of each student's fingerprint (Figure 2).

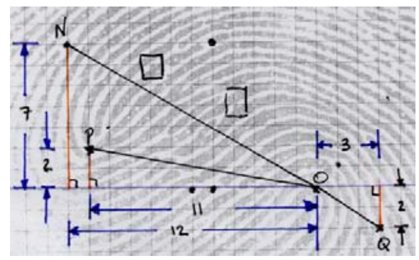

FIGURE. 5
FINGERPRINT CLASSIFICATION ALGORITHM DEVISED BY STUDENTS.

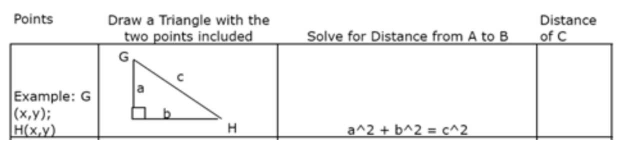

FIGURE. 6
EXAMPLE OF STUDENT FINGERPRINT MINUTIAE ALGORITHM WORKSHEET USING PYTHAGOREAN THEOREM.

FIGURE. 7
STUDENT FINGERPRINTING ACTIVITY (LEFT) AND EXAMPLE INDIVIDUALIZED WORKSHEET (RIGHT).

Phase 4: Elaborating the Concepts

The next class period, we handed out the individualized worksheets that superimposed a fingerprint of each student on graph paper (Figure 7). The purpose of today's activity was to allow students wo use their new knowledge and contiue to explore it functionality. Each student was tasked to work independently to map the core, five ridge endings, and five bifurcations (10 total minutiae points) and perform the calculations using the Pythagorean Theorem on a worksheet similar to Figure 6. The instructor's role was to troubleshoot, answer questions, and keep students on task. If students finished early, they were asked to read *Who Killed Cock Robin?* by K. O'Malley, a mystery and problem solving book about a person who faked his own death that the literature teacher assigned in coordination with this biometric lesson.

Phase 5: Evaluating the Lesson

To conclude this lesson, a fictitious crime scene was created, where a set of calculators were supposedly stolen. A local Crime Scene Investigator from the Lafayette Police Department was invited to come to the class and dust for fingerprints and discuss fingerprinting from a law enforcement perspective and how evidence is collected. For scalability, this was videotaped and played back during the remaining classes.

After the police investigator left, a video clip of how a crime scene investigators work in teams; that it is a team of individuals working together not one individual doing everything, which is commonly portrayed on television. It was then stated that the investigator collected the evidence for us and that it was the students' job to find out who stole the calculators using their fingerprint identification algorithm using Pythagorean Theorem algorithm students had worked on. A worksheet was created as evaluation for the lesson. Students had a class period to complete the evaluation. To ensure students actually did the work, each class had a different "criminal" and list of suspects. The evaluation sheet is shown in Figure 8.

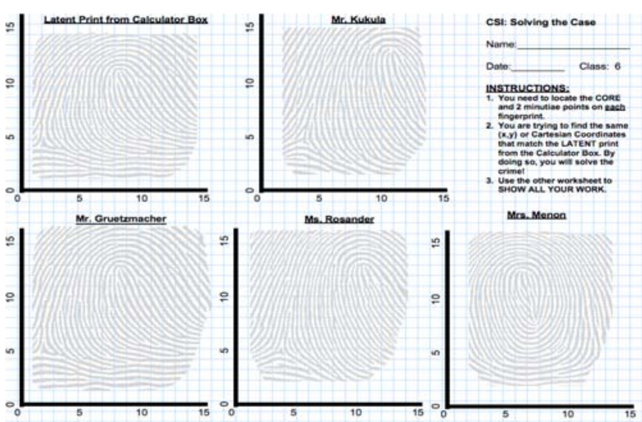

FIGURE. 8
LESSON EVALUATION WORKSHEET USED TO SOLVE THE "CRIME".

Conclusion

This paper was written to disseminate how an emerging technical area of biometrics and research can be integrated into the K-12 environment to enhance STEM education and inspire students' interest in science and math. The program presented in this paper utilized an inquiry based approach that centered on the 5E Instructional Model. Throughout the lesson the students were engaged and captivated, and either did not realize they were learning a mathematics skill (Pythagorean Theorem) or enjoyed the practical usage of using it to identify fingerprints. In terms of subjective assessment, the mathematics teacher stated that she did not have as much difficulty explaining Pythagorean Theorem to the students as she had in previous years, which was confirmed with the assessment scores of the final evaluation (Figure 8) that measured student's understanding of, and application of the Pythagorean Theorem. However, the teacher stated that students had issues with the Pythagorean Theorem when they were not solving for the hypotenuse, which was not included in the biometrics lesson. In the future, this could be implemented in the lesson as a supplementary component. Another lesson learned was the underestimated amount of time required to create the individualized fingerprint worksheets for each student. While it was worth the effort, this must be planned for if attempting to adopt this lesson. Additionally, the biometrics program is scalable depending on student skill level. For students with fewer skills, the classification scheme can simply use Cartesian Coordinates. Alternatively, for students with advanced skill sets, trigonometry concepts can be added to determine the angle of the minutiae point, which increases the complexity of the algorithm, but is also a defined method in the fingerprint minutiae data standard [9].

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