An Innovative Approach to Secondary Mathematics for Engineering and Science

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***Abstract*—The purpose of this paper is to provide a framework for NICERC's Advanced Math for Engineering and Science (AMES) curriculum that will lead to a series of studies on various aspects of the curriculum. Included in the paper is a description of the content, an explanation for the integration of AMES with other curricula, and a description of the professional development for AMES. AMES is a high school curriculum aimed at integrating multiple disciplines in order to provide context for the mathematics concepts used daily by engineers and scientists.**

This paper begins by discussing the structure of AMES. The structure is based on an analytic geometry approach to concepts taught in high school and post-secondary institutions combined with a multidisciplinary approach providing the context. Additionally, the paper outlines a broad description of the content in AMES and how multiple disciplines such as history, physics, and American government are incorporated into various lessons. This paper then demonstrates how other curricula are interwoven into AMES. Lastly, the paper includes a description of the professional development component of AMES. This section discusses how the professional development engages teachers prior to implementing the course.

Keywords—mathematics; interdisciplinary

I. Introduction

Secondary mathematics is usually presented as a subject that stands alone and is not related to other subjects taught in high school such as history or English. However, students enrolled in interdisciplinary classes experience advancement in metacognitive skills and critical thinking [1]. This suggests that classes should contain interdisciplinary components. Furthermore, there has been a recent push for teaching engineering in K-12 schools to foster higher achievement and greater interest in science, technology, engineering, and mathematics (STEM) courses and fields [2,3]. Along with this, as the Common Core standards are being implemented throughout the United States, curricula must be created that support these new standards. The Cyber Innovation Center, a 501c3 not-for-profit, is currently developing Advanced Math for Engineering and Science (AMES), a curriculum that integrates various STEM and liberal arts disciplines and meets mathematics and English language arts standards set forth by Common Core.

II. Curriculum Structure

The Advanced Math for Engineering and Science curriculum is being created using an analytic geometry base. The content, however, stretches past analytic geometry in order to integrate seamlessly with other engineering and science topics as well as topics in liberal arts disciplines.

Analytic geometry was chosen as the base due to the widespread use of representing geometric models in an algebraic form in order to solve engineering and science related problems. Evidence of this can be found in entry level engineering classes. For example, in the Statics and Mechanics of Materials text book by Riley, Sturges, and Morris, the first 70 pages are devoted to topics such as vectors, free body diagrams, and finding rectangular components in more than one dimension [4]. Another example of this can be found in "Engineering Dynamics" by Kasdin and Paley. Four out of the five major parts of this text are titled, "Particle Dynamics in the Plane," "Planar Motion of a Multiparticle System," "Relative Motion and Rigid-Body Dynamics in Two Dimensions," and "Dynamics in Three Dimensions" [5]. All of these are titles that suggest the student should be highly competent of coordinate systems and comfortable with switching between a coordinate system and the algebraic representation of the figures in that coordinate system.

The incorporation of other disciplines in AMES provides a new aspect to mathematics in the high school classroom. An example of this integration is that students will be required to learn the history of the mathematics they are studying throughout the course. They will be required to keep a timeline that includes major historical events, such as the opening of certain trade routes and notable national and international conflicts. The purpose of this is for students to provide a context for the discovery of new mathematics ideas and when these ideas were first studied. Another example of this multidisciplinary approach is a lesson devoted to applying mathematics to governing laws through axiomatic methods. The purpose of this is for students to apply higher level mathematics concepts to tangible ideas and practical scenarios.

III. Curriculum Content

Studies have shown that post-secondary freshmen and sophomore students lack essential mathematics skills required in engineering and science courses [6]. For example, in a study done by Aung, Underdown, and Qian, freshmen and sophomore engineering students received low scores when quizzed on the equation of a line, finding the dot product of two vectors, and working with matrices [7]. Because of this, the designers decided to include three essential threads: Coordinate Systems; Vectors, Matrices, and Axiomatic Methods; and Conic Sections. Each thread is composed of multiple units (e.g., Cartesian coordinates or polar coordinates), and each unit is composed of various lessons relating to the topic of the unit. Lessons include items consisting of the lesson notes, research assignments, the historical construction of mathematics, hands-on projects, and supplementary exercises intended to be used at the teachers' discretion.

More specifically, the mathematics content includes but is not limited to the following:

- Cartesian/Rectangular Coordinates
- Polar Coordinates
- The Imaginary Plane
- Three Dimensional Space
- Vectors
- Matrices
- Axiomatic Methods
- Conic Sections

Although several sections cover topics students may have already discussed in the past, the curriculum takes a different approach, or point of view, to the learning process. For example, in the unit on polar coordinates, students are required to derive the sine and cosine values of the special angles given a pair of sine and cosine values of one angle instead of being given a completed unit circle with each sine and cosine value previously computed. This will allow the students to practice pattern recognition, a fundamental concept in mathematics.

In some lessons the students are required to research various mathematicians and the history/creation of mathematics topics and present their findings. The purpose of this is to have students discover how the mathematics of the past developed over time into the mathematics used today. By doing this, students are also taught to communicate the mathematics they are learning in a variety of ways such as papers, presentations, and informally through group work.

Lastly, the students are required to complete hands-on projects that allow them to see where the mathematics occurs outside of the classroom. This project-driven approach in AMES curriculum allows the students to focus more on the mathematics being taught instead of the project being completed [8]. For example, the students will create a tension mechanism and study the forces in the system while studying vectors and vector components. While it is fun for the students to construct the mechanism, they will spend more time drawing free body diagrams, calculating tension, and finding vector components when various weights are applied to the system.

IV. Integration of Other Curricula

NICERC has previously developed its Physics curriculum and Cyber Science curriculum. While developing the AMES curriculum, NICERC is also developing a middle school course, STEM Explore, Discover, Apply (STEM EDA). Since mathematics is not a topic that exists alone, the developers of these curricula are integrating each previously developed course with AMES. This integration will provide connections for the students who are simultaneously taking or have previously taken these courses and provide potential research opportunities. Although these courses can be used to build upon each other, AMES could function as a stand-alone course as well. Also, in order to meet the changing standards, Common Core State Standards (CCSS) will be used throughout the course.

The Physics curriculum takes a project-driven approach to teach electricity and magnetism, work and mechanics, waves and sound, light and optics, and thermal fluids. The AMES curriculum will integrate with the Physics curriculum by focusing on the mathematics fundamentals used in Physics. This will allow students to deepen their understanding of the underlying principles that describe the physics phenomena being studied. The desired outcome is that students will enter college feeling comfortable about the mathematics used in the physics topics listed above.

The Cyber Science curriculum teaches cyber concepts and fundamentals to high school sophomores and juniors. In order to do this, the students use a robotics platform and conduct ethical and historical discussions about cyber. The AMES curriculum expands upon the skills Cyber Science students developed holding ethical and historical discussions and focuses them on mathematics. This allows students previously enrolled in Cyber Science to continue to develop their technical communication skills. Where applicable, the same robotics platform will be used to teach the application of mathematics topics included in AMES.

The STEM EDA course focuses on using the engineering design process as a guide for engaging middle school students in STEM. AMES will take the engineering design process and apply it to mathematics with the intent of showing how the engineering design process can be used in various disciplines, showcasing the interconnectivity of these disciplines, and reinforcing the engineering concepts they have previously learned.

As it is pertinent to new curricula, AMES will meet several of the standards set forth by the Common Core State Standards. Keeping in mind that many of the topics covered in AMES are more advanced than the topics covered in the CCSS, several of the lessons will exceed CCSS for mathematics. Also, since several topics students have previously learned are covered in more depth, AMES contains a cross course overlap of CCSS. Furthermore, there will be several lessons that will satisfy many of the CCSS for English Language Arts for 11^{th} and 12^{th} grade since the students will be constructing content specific documents throughout the AMES curriculum [9].

V. Professional Development

Often, teachers are given little to no training with unfamiliar curricula they are required to teach. Similarly, teachers typically do not have the opportunity to provide feedback on the curricula. AMES will provide teachers with professional development training that allows them to become familiar with and provide input on the curriculum. The professional development is immersive in the sense that the teachers can learn about the content from a student's point of view. Also, after the professional development workshops and throughout the year, the teachers will be asked to provide feedback on the curriculum in order to make improvements. Furthermore, the professional development provides an overflow of information to allow the teachers to learn the structure and content of the curriculum deeply. Finally, during the professional development workshop, teachers will be given all the physical and cognitive tools needed to teach the course.

VI. Conclusion

Since the Advanced Math for Engineering and Science curriculum is still in development, the various aspects mentioned in this work are subject to change between now and the piloting of the course. The first professional development workshop will occur during the summer of 2013. The course will then be piloted at the schools that have teachers participating in the summer workshop.

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