LEVERAGING INTERDISCIPLINARY EXPERTISE IN DEVELOPING AN ALTERNATIVE MATHEMATICS PATHWAY

Beverly Wood
Embry-Riddle Aeronautical University
Beverly.Wood@erau.edu

Debra T. Bourdeau
Embry-Riddle Aeronautical University
Debra.Taylor@erau.edu

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ABSTRACT
How many instructors does it take for amazing course design? Or perhaps we should begin with "A mathematician, humanist, communication expert and statistician walk into a bar." This unlikely team has co-developed a pair of courses, Learning to Reason I: Art and Quotient and Learning to Reason II: Commerce and Flux, that deeply investigate quantitative reasoning from multiple perspectives. Blending elements of rhetoric, logic, and history with mathematical computation, representation, and application breaks through the perceived barriers between the unyielding, obstinate world of mathematics and the ambiguous, equivocal world of the humanities. Developing the courses as an interdisciplinary team of mathematicians and humanists has brought together multiple ways of reasoning and habits of mind that present students with experiences in critical thinking involving both numbers and words. These innovative courses investigate such diverse topics as the history of mathematics, ethics and statistics, mathematical art, logical fallacies, fun with spreadsheets, personal economics, communicating quantitatively, and even origami. These courses also provide an alternative mathematics pathway for students in our programs for which calculus is not required. This paper will examine this unique interdisciplinary course development experience that uses an asynchronous online modality to deliver content to students around the world.

KEYWORDS
STEM, humanities

In recent years, it became evident that some students at STEM-focused universities face the same challenges in learning mathematics as adults returning to education later in life at institutions of all types. Jameson and Fusco (2014), for example, document lower levels of mathematics self-efficacy in adult learners while also noting that math anxiety is higher in non-traditional students. Compounding this issue, few degrees at Embry-Riddle Aeronautical University (ERAU) do not require one of the two versions of calculus (polynomial calculus and engineering calculus) that are offered. However, some degree programs allow for a choice between pre-calculus/polynomial calculus or college algebra/trigonometry for meeting the general education requirement of completing six credit hours of mathematics. These include non-STEM programs in Interdisciplinary Studies, Communication, Emergency Services, and Homeland Security. Given that there are several programs whose disciplines do not demand the skills represented in the Student Learning Outcomes (SLOs) for either of the existing options, there was clearly room for an alternative mathematics pathway for students in these non-STEM majors (Saxe & Braddy, 2015).

To accommodate these students, an initiative in the ERAU College of Arts and Sciences was created by two faculty who were working across different departments, Dr. Bourdeau (a humanist) and Dr. Wood (a mathematician), to include interdisciplinary perspectives in general education courses – Humanistic STEM (H-STEM). This initiative was underway when ERAU joined the NSF funded national consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P) in the fall of 2019. While H-STEM focuses on crossing the boundaries of meta-disciplines to create multiple lenses of inquiry (Bourdeau & Wood, 2019), SUMMIT-P utilizes a robust collaborative process for mathematics faculty to work with faculty from client disciplines (physics, engineering, business, etc.) to improve knowledge transfer for students. These processes do not seem limited to only mathematical preparation for STEM fields but, rather, are useful in both STEM and non-STEM collaborations. Together, both projects stressed the need to eliminate disciplinary silos in a way that shows students the connections between their academic experiences and underscores the relevance of knowledge and skills from the classroom to the workplace.

Based on the history of success in STEM and STEM-adjacent (healthcare and business) collaborations through SUMMIT-P, faculty from the Humanities and Communication department and the STEM Education department worked together to create an alternative pair of mathematics courses that would meet the requirements of the ERAU general education Quantitative Reasoning competency without the rigid constraints of preparing students for calculus. The interdisciplinary team of content creators offered a variety of activities that demonstrate wide applicability of mathematical concepts in other disciplines as well as in common life experiences. The design collaboration is evident in materials developed to model the deep connections across disciplines and the meta-disciplines of STEM and humanities.

Listening to the Partner Discipline

After determining that an alternative pathway was needed, we chose to initially focus on one non-STEM degree, the Bachelor of Science in Communication. It was selected for its small size (approximately 36 students) and the fact that it is a shared program across two of the three ERAU campuses with an existing strong, collaborative relationship. The first step in developing a set of courses that would provide students with mathematics skills relevant to the communication discipline was to determine what those skills actually are. This was handled by

providing communication subject-matter experts with the opportunity to explore and explain how mathematics impacts the discipline and what graduates need to know to be successful in the field.

To initiate the collaboration process, the fishbowl discussion technique (Hofrenning et al., 2020) was used. This technique involves an idea-sharing discussion of one group while a group of listeners observes, this protocol gave mathematics faculty the opportunity to listen to communication faculty from both campuses as they talked about the quantitative aspects of the careers for which their students are preparing. Fishbowl participants included mathematics faculty, who served mainly as observers but who could answer curriculum-specific questions as needed. A facilitator guided the discussion. Communication faculty responded to the facilitator's questions about how mathematics is used in the communication discipline. These predetermined questions are part of SUMMIT-P protocol (see https://www.summit-p.com/resources/collaboration-tools). Topics that emerged from this discussion included the importance of designing effective data visualization, the need for ethical reasoning in mathematics, and the application of problem-solving skills.

Based on that conversation, a list of learning outcomes was developed for two new courses, MATH 201 Learning to Reason I: Art and Quotient (see Table 1) and MATH 202 Learning to Reason II: Commerce and Flux (see Table 2). Some of the assignments such as preparing an annual budget for a human trafficking shelter or using design principles for presenting that budget fell clearly into disciplinary silos, while others were more collaborative by nature. For example, writing instructions to create origami using geometrical language.

Table 1

MATH 201 Student Learning Outcomes

1. Interpret verbal and visual media presentations of data.
2. Design effective data visualizations.
3. Apply proportional reasoning in multiple contexts.
4. Describe the ways that geometry appear in the natural world and art.
5. Distinguish between inductive and deductive reasoning.
6. Select appropriate technologies to compute, analyze and interpret information.
7. Recognize ethical dilemmas in dealing with quantitative information.
8. Identify the intellectual and cultural context in which mathematical progress has occurred.

Table 2

MATH 202 Student Learning Outcomes

1. Demonstrate financial literacy.
2. Critique multiple pathways to mathematical solutions.
3. Explain the logic of quantitative reasoning processes.
4. Manipulate mathematical functions in applied problem-solving.
5. Distinguish between inductive and deductive reasoning.
6. Select appropriate technologies to compute, analyze and interpret information.
7. Recognize ethical dilemmas in dealing with quantitative information.
8. Identify the intellectual and cultural context in which mathematical progress has occurred.

The Courses

Two three-hour courses were developed to meet the general education requirement of a six-hour math series. The course description, topics (see Table 3 and Table 4), and a sample activity for each course are described below.

MATH 201 – Learning to Reason: Art and Quotient

Title. The developers decided that a unique, eye-catching title that captured the interdisciplinary nature of these courses while relaying the focus areas of each was important. Specifically, proportionality, statistics, and probability, the areas of mathematics that emerged from the fishbowl discussion, are included. Additionally, a bit of trigonometry – supported by the Pythagorean Theorem – makes up the Quotient portion of the course. The Art portion includes origami, mathematical art exhibition, and exploration of the multiple meanings of the term "aspect ratio."

Catalog Description. The course addresses both the abstract and applied aspects of data science, proportionality, and geometric concepts. Exploration of the development of mathematics and the modern technologies used to apply ancient ideas to today's problems as well as the human need for creativity across disciplinary boundaries.

Table 3
Weekly Modules in MATH 201

Module 1	Where does math come from? History of mathematics / Timeline project
Module 2	Innocent until proven guilty: Logical fallacies / Proving the Pythagorean Theorem
Module 3	What are the chances? Monty Hall problem / Probability practice
Module 4	Do numbers lie? Professional ethics for statisticians / Data visualization
Module 5	A picture is worth a thousand words: Critique data visualizations / Association and correlation
Module 6	Five out of four people have trouble with fractions: Special ratios / Writing a press release with quantitative information and visuals
Module 7	The geometry of life: Origami / Perimeter, area, and volume
Module 8	The life of triangles: Ratios and proportions / Completing the timeline project
Module 9	Quantitative creativity: Find and describe art with mathematical language / Learning reflection

Assignment Example. Triangles of Life discussion (the penultimate module) requires students to make an audio/visual presentation of triangles they encounter in daily life or in vacation photos or from internet sites featuring places they would like to go. It should be noted that the initial offering of the course was in the fall of 2020 during the COVID-19 pandemic. Not only were they to find an image but also to explain whether it was included for aesthetics, structural integrity, or both, using appropriate mathematical language. For example, a "pentagonal pyramid roof" of a backyard birdhouse with edges of length "3.5" x 3" x 4"" which were used to determine that it was a scalene triangle. This assignment assessed not only the understanding of mathematical vocabulary but also the integration of symmetry and asymmetry into human environments, creating multiple lenses of inquiry. Students were required to make at

least three discussion board posts about their findings. (For interested readers, the full syllabus can be found at www.humanisticstem.com.)

Grading. Student work is assessed via rubrics. The rubric's scoring guide includes points that apply to both disciplines (see Figure 1).

Figure 1

Rubric for Triangles of Life Assignment

MATH 201 Module 8 Converse Triangles of Life Rubric

You've already rated students with this rubric. Any major changes could affect their assessment results.

Criteria	Ratings			Pts
Timeliness Initial post is made no later than the end of the fourth day of the module.	10 pts On time	0 pts Not on time		10 pts
Finding Triangles Photo, video, or artwork of three triangles presented visually.	20 pts Three	10 pts Two	5 pts One	20 pts
Communicating mathematics Appropriate use of mathematical language to describe each of the chosen triangles and their beauty or utility.	30 pts Well done	20 pts Good work	10 pts Could be better	30 pts
Participation Responding to classmates' posts about your initial post and replies to at least two classmates' initial post with your remaining two triangle images/commentary.	30 pts Well done	20 pts Good work	10 pts Could be better	30 pts
Writing is professionally done, including current APA citations where needed.	10 pts Perfect	5 pts Readable	0 pts Poor	10 pts
				Total Points: 100

Student response. "I thought this was a really fun assignment," said the student who found an amazing number of triangles in their home décor. There was excellent engagement of all students, including finding additional triangles in their neighborhoods after seeing what other classmates found. Everyone in the class exceeded the required three posts in this discussion. The posts were unusually substantive.

MATH 202 – Learning to Reason: Commerce and Flux

Title. Additional topics that were suggested by communication faculty to be included in the course were experience with Excel, economic indicators, and understanding of mathematical vocabulary. A third of this course covers financial literacy with modules on the order of operations, functions, and basic calculus topics (using Desmos).

Catalog Description. A quantitative approach to life's decisions, addressing both the abstract and applied aspects of using mathematics in finance, technology, and design. Exploration of the development of mathematics and the technologies used to assist in decision-making.

Table 4
Weekly Modules in MATH 202

Module 1	Mathematical reasoning: *Mathematics for Human Flourishing* by Francis Su / Concept map of development of mathematical thinking
Module 2	Order of operations: Technical writing of instructions / Critique of student errors in sample exam
Module 3	Functions, relations and equations: Stepwise functions / Function families
Module 4	Fun with spreadsheets! Microsoft Excel training / Creating a budget for a human trafficking shelter
Module 5	Personal economics: Loans and credit / Present value, future value, and compound interest
Module 6	Economic indices: National economic indicators / Interest rate and amortization
Module 7	Communicating quantitatively: Critiquing economic articles / Presentation of economic concepts
Module 8	Quantifying change: Roller coaster calculus / Optimization
Module 9	Mathematicians are human: Mathematical disputes / Final concept map

Assignment Example. Following the module devoted to functions, and as an introduction to the financial unit, students are asked to create a budget for a human trafficking shelter under the assumption of a linear increase of clients over the course of the year. This project was inspired by the discussion with communication faculty that revolved around the skills that could be learned by using Microsoft's free, online Excel tutorials. The budget allows students to blend mathematics tasks with social concerns within the context of financial responsibility.

Student response. "Excel opens up so much and has an endless [number] of functions you can use it for." and "I'm really happy that you all decided to include Excel as a significant portion of this course. It will be SO valuable [in the future]."

The Faculty Experience

The faculty collaboration that produced MATH 201 and 202 was not without its challenges. One of the pitfalls of both team teaching and team development is the propensity for administrators to assume that each additional team member will certainly result in less work for everyone involved. The result is often less pay or divided course "credit" for team-developed or team-taught courses. Some institutions, not wanting to navigate the murkiness of the issues simply discourage (or even disallow) the practice. Some departments are reluctant to allocate precious and scarce faculty time when the resource will be shared with another unit.

Compounding these issues is the reality, of course, that team teaching and team development often involve the added elements of strategy meetings, division-of-labor discussions, conflict resolution, and additional editing complexities. Rather than lessening the workload, solid course development or teaching collaboration will increase the work required of all team members. Without administrative understanding or support, this fact can discourage classroom collaborations altogether or, at the very least, create a process steeped in frustration. Absolute buy-in from administrators is the first step in creating an atmosphere in which fruitful collaboration can occur.

When these obstacles are overcome, a team will then need to maneuver through other issues that can arise in interdisciplinary teams including varying expectations about writing quality, research methodology, assignment design, rubric deployment, and teaching philosophy. Discussions surrounding these concerns can be complex and seemingly unresolvable. Some of the questions that arise include: Should students compose lengthy written arguments? If so, who grades them? Should class sessions be focused on lectures or discussion? Is homework an essential element of the course? Are mechanics and style essential elements of written work? To what extent? These kinds of questions often led to the need for compromise in places where the disciplines had differing expectations. Navigating disciplinary diversity requires handling conflict in a way that moves the project forward.

The development of MATH 201 and MATH 202 included collaborators from four disciplines: mathematics, statistics, humanities, and communication. Each collaborator prepared mini-lecture recordings to be used in the courses. Some collaborators developed complete activities. Everyone engaged in the co-development of course assignments. Each person had different ideas about what concepts a course in their discipline should include, the types of assessments that were appropriate to ensure attainment of SLOs, and the appropriate workload for students. Additionally, while the courses would contain both humanities- and communication-focused elements, it was essential that there was sufficient mathematics content, to justify the MATH prefix and to ensure that students could use the courses to fulfill general education requirements in that area. The team had to agree to keep mathematics at the forefront while not diminishing the humanities and communication content which would have made those components seem less than fully integrated into the courses.

The humanist on the team, also a collaborator on the H-STEM project, determined that it was important that students see the connections between mathematics and arts/humanities. First, she wanted them to consider how mathematical elements were expressed in visual art. As a result, paintings by Crockett Johnson (1974) appear in each module of both courses. See Figure 2. Johnson's focus on mathematics and physics in his paintings makes him an ideal "guide" through the course, consistently reminding students that these worlds are not as distinct as they might imagine. These connections are reinforced in lessons throughout the course.

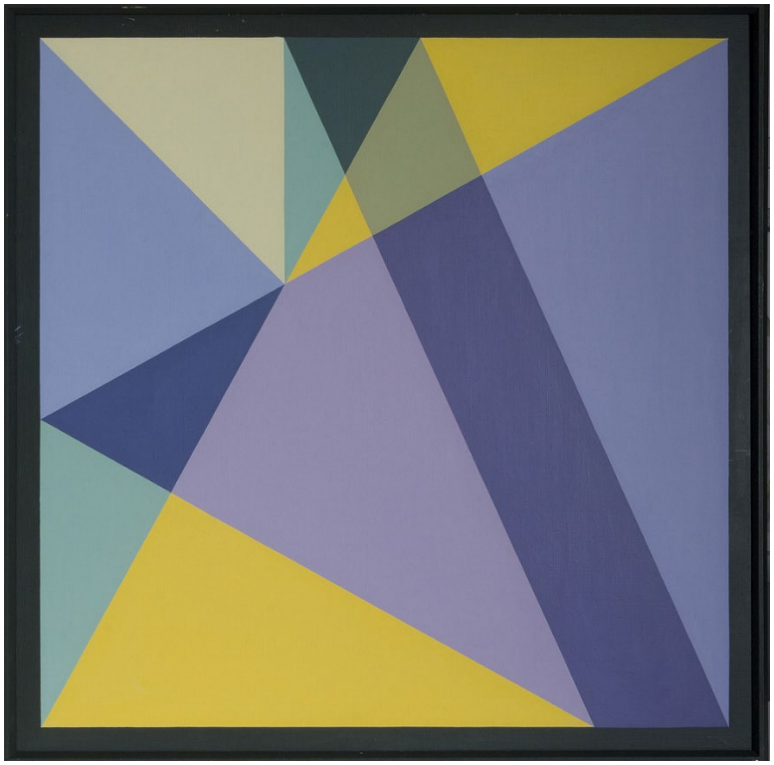
In the course, students are encouraged to create their own mathematical art through a work of origami. They are told that while they "will not be expected to construct a nonagon or a cubical parabola," they must create a set of instructions for their classmates to follow in their own attempts at paper folding.

Another module explores the connections between logic and mathematics by introducing students to both mathematical proof and logical fallacies. Not only do the students attempt to find real-world examples of fallacious arguments, but they also must select one of the 118 unique proofs of the Pythagorean Theorem to present in their own words. The rubric for this assignment reflects the humanities/mathematics blend, with an equal number of points awarded for communication of concepts and mathematical accuracy. These activities reflect the interdisciplinary nature of argumentation, reinforcing the value of these skills across their educational experience.

While it was easy enough to write these humanities-focused assignments from a disciplinary standpoint, the mathematicians on the team ensured that the team was tethered securely to the mathematical concepts in the course. Rather than simply "sprinkling in" the humanities, the selected assignments are fully integrated and pedagogically relevant. As

discovered through the humanistic STEM discussions, this "blend" is the real strength of the collaboration.

Figure 2
Crocket Johnson (1974). Archimedes Transversal. Smithsonian National Museum of American History. Washington, DC.



Similarly, the communication faculty wanted to be sure that students could read, create and interpret data visualizations that would be needed in business contexts such as a press release or slide presentation. They also insisted that the courses include some discussion of ethics specific to data visualization and statistics. As a result, students created a moving average time series of economic data from the Bureau of Labor Statistics using Excel and writing about the line plot. The rubric for grading this assignment was evenly split between the quantitative accuracy and the communication of what the graphic reflects about the data. Using Edward Tufte's (2001) Principles of Graphical Excellence as discussed in his *The Visual Display of Quantitative Information*, students are asked to critique examples of effective and ineffective representations of data. Students use the Associated Press (2020) Stylebook to compose a press release using results from previous statistical assignments. The communication faculty also had an impact on the layout of the course; module landing pages were presented in an infographic style to illustrate visual communication.

While maintaining the humanities and communication content that was so important to those members of the team, the mathematician faculty worked to ensure that the courses connect these disciplines effectively to mathematics and at a sufficient level of quantitative competency to be a course worthy of the MATH prefix. During the fishbowl activity with Communication and Humanities faculty, the mathematics faculty listened as the faculty shared topics in their

disciplines related to quantitative reasoning and statistical literacy. These specific topics are included in the first four SLOs for each of the courses (Tables 1 and 2). The remaining four SLOs are identical in both courses and blend the elements where the seemingly disparate disciplines have overlap and usefully inform one another. The mathematician's role was to ensure that the blended elements balanced the concerns of all four disciplines without obscuring the quantitative objectives of a mathematics course.

Achieving multi-level buy-in for such a complex course development project is another challenge that required a team effort. At ERAU, the Instructional Design and Development (IDD) department had to be persuaded that the expertise of *four* faculty developers (instead of the typical one or two) added value to the project. It was an admittedly unusual request for a process that typically pairs one faculty subject-matter expert with one instructional designer. Designating one point of contact for communication with IDD assuaged some of the concerns. Typically, the instructional designer's meetings were held specifically with the individual serving as the point of contact, with only occasional full-team meetings at integral points in the development process. This eliminated the possibility of multiple, even competing, points of view being expressed in design and development meetings. The point of contact obtained the consensus of the team before representing the group in design meetings.

Anticipating concerns about faculty credentials for such an interdisciplinary course, the development team worked to ensure that the course (prefixed as a mathematics course) did not require specialized knowledge in humanities or communication that would prevent a mathematician from having mastery of the course material. Additionally, the humanities and communication faculty team members developed extensive background pieces to fully contextualize each activity. Finally, thorough explanations were added to the "Information for Instructors" area of the asynchronous course. Because ERAU uses a course template model for course development, these resources are available to instructors who were not part of the development team.

Student Responses

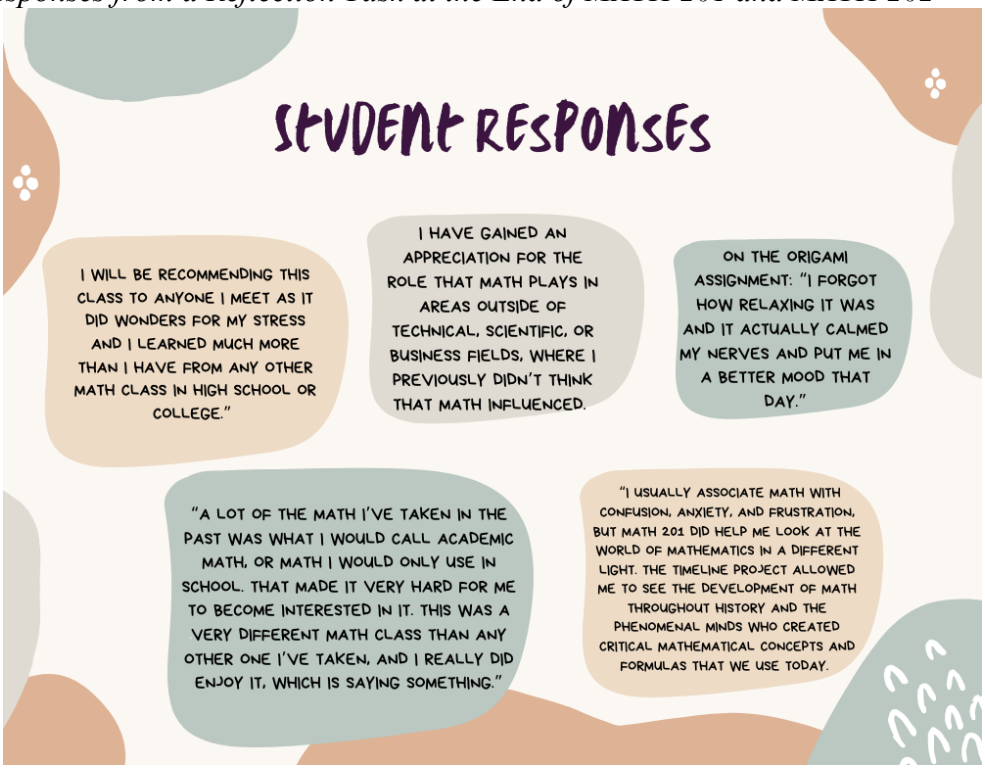
While the courses are too new to provide longitudinal data, students have been responding favorably to the educational experience as evidenced by their end-of-course evaluations. Responses have focused on the practical application of the skills reinforced in the courses as well as how the classes were able to alleviate math anxiety. A selection of student responses appears below (see Figure 3).

Sustaining the Project

This project shows significant potential for long-term sustainability. The STEM Education department publicized the course to increase interest among potential instructors. Because most courses are staffed by adjunct faculty, it is essential to create clear lines of communication about new initiatives. A list of faculty interested in teaching the courses was compiled. In Fall 2021, MATH 201 was taught by a faculty member who did not serve on the development team. Dr. Wood worked closely with the adjunct instructor to ensure that the course delivery aligned with the philosophy of the course development team. After teaching MATH 201, this instructor commented to the team, "Thank you for creating such a wonderful class!!! I very much enjoyed teaching MATH 201 and am looking forward to MATH202."

Figure 3

Student Responses from a Reflection Task at the End of MATH 201 and MATH 202



Since their initial offerings, there have been conversations with advisors and the program chairs about adding the courses as options for three additional degrees. Because of the MATH prefix, the courses belong to the STEM Education department with the mathematician on this project as the nominal course monitor. The collaborative development, however, leads to further teamwork when questions of content or pedagogy arise. College policy dictates regular redevelopment of online templates which will be opportunities to bring the developers back together. This will be in addition to the informal conversations about student interest and performance in the courses as well as reviewing the end-of-course student surveys. New faculty are being recruited to teach an additional section of each in the upcoming academic year.

Importantly, the individuals involved in College's H-STEM initiative are highly supportive of these two mathematics courses and are actively looking for additional course collaborations between the STEM faculty and faculty in other departments. For example, Baseball History and Statistics is a course currently under development as a collaboration between mathematics and history. Next is the redevelopment of a course, Digital Humanities and History of Communication Technology, that will feature collaborative reviews to integrate the STEM perspective more deeply into the curriculum of the Humanities and Communication departments.

Finally, the team has an active dissemination schedule, including presentations at conferences in multiple disciplines, from the National Numeracy Network to the Northeast Modern Language Association. Providing a model for successful interdisciplinary course development, the team has additional contributions planned for both the multi-institutional SUMMIT-P project as well as the ERAU H-STEM initiative.

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