Project Description

1. Innovations in Graduate Education

1.1. Overarching Project Goals

The proposed project aims to address communication issues in STEM graduate students' interdisciplinary teams, with a focus on breaking down knowledge barriers, mitigating biases, and enhancing the sense of belonging. This will be achieved through the customization and innovative use of Artificial Intelligence-Generated Content (AIGC) tools (e.g., ChatGPT, Notion AI, WordAI, Midjourney, and DALL-E2).

The proposed approach comprises two research projects that specifically aim to address communication issues in interdisciplinary teams as outlined in Figure 1. The first research project will explore how to customize text-based AIGC tools to generate a hierarchical knowledge structure to break down knowledge barriers; the second research project aims to use graphic-based AIGC tools to mitigate bias and enhance the sense of belonging of interdisciplinary team members. These two projects will serve as the foundation for developing innovative, transferable, professional intervention, which includes three training modules and an interdisciplinary team project. We will conduct three rounds of pilot training to iteratively test, assess, and improve the proposed methods and training materials. We will evaluate the proposed intervention for its effectiveness and efficiency in mitigating the identified challenges. The project team will deploy and pilot the 4-month training during the fall and spring semesters with set times in a computer lab in the College of Aeronautics and Engineering (CAE) building, with targeted graduate students from programs such as M.S./Ph.D. in Aerospace Engineering and Mechatronics Engineering and M. Engineering Technology from CAE, and M.Ed./Ed.D./Ph.D. in Educational Technology from the College of Education, Health and Human Services (EHHS). Project materials will then be made available to all higher education institutions in an open-access format.

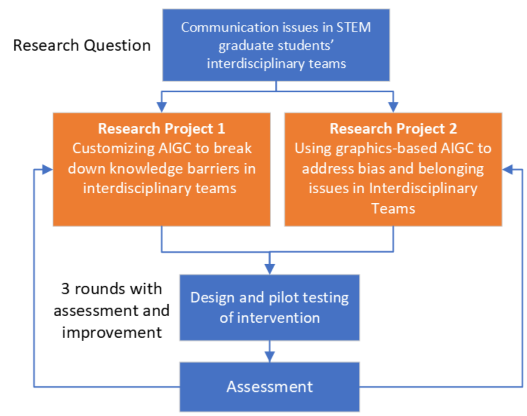


Figure 1. Overview of the project

The expected outcomes of this project are three-fold. First, the research will provide broad evidence of the ways in which AIGC can be used to improve graduate education. Second, the research will provide specific data related to the ways in which AIGC can identify and reduce bias, improve the sense of belonging, and reduce knowledge barriers for interdisciplinary STEM teams. Third, the development and dissemination of an open-access professional training program can equip STEM graduate students with the knowledge and practical skills needed to customize AIGC tools to better prepare them to work and contribute to interdisciplinary teams. Upon completion of the training, students will be able to apply these skills in their future interdisciplinary collaborations and contribute to more effective and inclusive teamwork.

1.2. Research Projects

1.2.1. Research Problem

Interdisciplinary research brings numerous technological breakthroughs for society. For instance, brain, cognition, and computer science teams have produced deep convolutional neural networks (Liu et al., 2017; Cheng et al., 2018), visual attention models (Borji & Itti, 2012; Mnih et al., 2014), super AI cheese player AlphaGo (Silver et al., 2017), and large language model GPT3 (Floridi & Chiriatti, 2020). The highly adaptive robot dog named Boston Dynamics Spot (Zimmermann et al., 2021) was developed by an interdisciplinary research team consisting of mechanical engineers, control engineers, and electrical engineers, computer scientists, and industrial design experts. The high-precision genome editing tool

CRISPR-Cas9 was created by an interdisciplinary team of molecular biologists, biochemists, and computer scientists (Jiang & Doudna, 2017).

Given the benefits of interdisciplinary collaboration, it is important to train student researchers (graduate students) to successfully work in interdisciplinary teams. However, interdisciplinary collaboration among graduate students has several challenges. Communication is often considered one of the biggest issues (Bracken & Oughton, 2006; Cummings et al., 2013) because interdisciplinary teams bring together individuals with diverse backgrounds, expertise, and perspectives, which can create challenges in communication and collaboration (Martynova et al., 2020).

In particular, interdisciplinary teams may face knowledge barriers, such as language barriers, differences in terminology and jargon, and differences in communication styles and expectations (Stahl et al., 2010; Martynova et al., 2020). These challenges can lead to misunderstandings, delays, and reduced productivity, which can ultimately impact project outcomes. Other significant communication challenges include social issues such as bias and a lack of belonging (Robertson, 2023; McClintock & Fainstad, 2022). Team members may have preconceived notions about other disciplines, which can lead to stereotypes and prejudices. This can undermine the trust and respect that are necessary for effective communication and collaboration (Woolley et al., 2010; Horn et al., 2022; Davis et al., 2022). Therefore, it is essential to create a culture of inclusivity and diversity, where all team members feel valued and respected, and actively listen to other perspectives and opinions.

This proposal aims to address communication challenges in interdisciplinary teams by utilizing AIGC tools in innovative ways. Specifically, we seek to overcome knowledge barriers, mitigate bias, and enhance the sense of belonging among team members.

1.2.2. Research Project 1: Customizing AIGC to break down knowledge barriers in interdisciplinary teams

Background and Motivation:

Several obstacles impede the establishment of effective interdisciplinary collaborations among graduate students. These challenges include:

1) Limited access to learning resources that facilitate collaborative progress: Effective coordination within a team necessitates resource support, such as equipment usage, learning materials (books, papers, slides, courses), and timely, professional guidance. It is imperative to help students identify knowledge gaps among members, determine the essential knowledge or guidance needed for advancing collaborations, and provide comprehensible guidance that inspires high-quality collaboration.

2) Students have different disciplinary backgrounds leading to ineffective communication. The knowledge and skills they use to analyze problems and develop solutions are different; their jargon in expressing professional ideas and formulating the logic of the problems they encountered are different. These differences create misunderstandings and communication barriers within the team.

Various approaches have been proposed to overcome knowledge barriers in interdisciplinary teams. For instance, there are cross-disciplinary courses and training programs, such as interdisciplinary degrees that allow students to select cross-school courses (Carnegie Mellon University, n.d.; University of California University System, n.d.). While these programs aim to help team members develop a basic understanding of other disciplines and their methodologies, they may not provide in-depth knowledge of each discipline, resulting in incomplete or inadequate solutions to interdisciplinary problems. Furthermore, such activities may require a significant investment of time and resources, making it difficult for all team members to participate. The use of data visualization software, such as Tableau Desktop (Tableau Software, 2021), and virtual reality, such as Unity (Unity Technologies, 2021), can help team members understand complex data and concepts from different disciplines. However, this may require additional technical expertise and/or extra equipment, creating barriers to adoption and use. Developing shared vocabularies and communication protocols is a common approach to improving interdisciplinary collaboration (Nahar et al., 2022; Chavarro et al., 2014; Borrego & Newswander, 2010). Although using standardized terminology and definitions can promote shared understanding and communication, implementing shared vocabulary can be challenging and time-consuming, requiring continuous effort to maintain as new vocabularies emerge during the project's progression.

To summarize, even though activities and technical means have been created and implemented to help facilitate interdisciplinary collaboration, these approaches have drawbacks such as time constraints, technical difficulties, and the need for additional resources, which can hinder their effectiveness in practice.

Artificial Intelligence-generated content (AIGC) tools have emerged as a transformative force in various fields, revolutionizing the way knowledge is generated, shared, and consumed (Radford et al., 2018). These advanced AI systems, such as OpenAI's GPT-series (Radford et al., 2018; Brown et al., 2020), utilize natural language processing and machine learning algorithms to produce contextually relevant and coherent content, spanning a diverse range of subjects (Brown et al., 2020). These tools can distill complex concepts into accessible language, bridging the gaps between disciplines and fostering a more collaborative and innovative environment for problem-solving. Furthermore, compared to traditional methods of acquiring the knowledge needed in a team project, AIGC has great potential to enable team members to access and assimilate information faster, easier, and more effectively.

However, there exist standing issues and concerns regarding the limitations and challenges of incorporating AIGC into educational settings. A significant issue is AIGC lacks domain-specific knowledge, which may produce erroneous or superficial information (OpenAI, 2023), undermining the quality of educational content and potentially misinforming students (Radford et al., 2019). Another issue is the possibility of generating toxic content as AIGC tools may inadvertently produce biased, offensive, or harmful information (National Cyber Security Center, 2022), particularly when operating in an unrestricted mode, such as a developer mode. This issue raises concerns about the ethical implications of using AIGC in educational contexts and the potential negative impact on students' learning experiences and well-being. Lastly, AIGC systems may sometimes generate content with illogical or incorrect information. Although these systems are designed to create contextually relevant and coherent and irrational content, they may occasionally produce outputs that lack logical consistency, contain contradictory statements, or deviate from established facts and principles (Petkauskas, 2023; National Cyber Security Center, 2022; Zellers et al., 2019). Such inaccuracies can hinder students' learning and comprehension, leading to confusion and misconceptions.

Proposed work:

We propose to provide a means to customize and use AIGC tools to generate specific domain knowledge that will serve to break down the knowledge barriers among interdisciplinary team members while ensuring the generated content is non-toxic, trustworthy, and logically correct. In research project 1, we will investigate methodologies to customize existing AIGC tools by integrating discipline-specific domain knowledge, and will also address the key concerns and issues of using AIGC tools in graduate education, such as the toxicity and inaccuracy of the generated content. Students will be trained in skills to customize AIGC tools and use them to analyze knowledge gaps between team members and translate terminology from other disciplines to obtain the required knowledge in a timely manner. Specifically, we will try to answer the following research questions and propose corresponding solutions.

Research Question 1.1 (RQ1.1): How can AIGC tools improve interdisciplinary communication by delivering domain knowledge?

Method: Integrating discipline-specific domain knowledge into AIGC to prepare it as a general knowledge tool for facilitating interdisciplinary collaboration.

Subtask a. Integration of domain knowledge into AIGC. Based on project requirements for interdisciplinary collaboration, such as project goals, system performance, key design elements, and project delivery guidelines, knowledge sources like slides, text materials, and images will be incorporated into the AIGC, transforming it into a knowledgeable resource. A systematic and hierarchical knowledge structure will be developed, which, in conjunction with AIGC's comprehension capabilities, will provide discipline-specific domain knowledge at the appropriate depth to support interdisciplinary student collaboration.

Subtask b. Identification of team members' knowledge gaps. Students' knowledge gaps can create communication barriers within teams. For instance, a biology student may be unfamiliar with Lidar sensors, making communication with engineering students challenging. With prompts from students, AIGC will serve as a gap analysis model to identify knowledge gaps in specific collaboration cases and retrieve the knowledge needed to bridge these gaps. The prompt will be defined as a dictionary covering important questions to resolve confusion in the collaboration, such as {goal{we will develop a prototype of the drone system}; context{it is for a graduate-level course project for course ENG1234 for Kent State University}; key communication issues{disagree on drone shape design; agree on sensor usage}; need suggestions {the shape enables the drone to fly fast; what is the Lidar sensor mentioned; which sensors are the best for small UAV's obstacle detection}}. Based on student discussions, this knowledge will be autonomously retrieved and provided to the students.

<u>Outcome</u>: Rich learning resources with in-depth domain knowledge will be provided to students; interdisciplinary collaboration will be improved in both efficiency and learning outcomes.

Research Question 1.2 (RQ1.2): What are the methods to ensure the knowledge generated by AIGC is non-toxic, trustworthy, and logically accurate?

<u>Method</u>: Develop a knowledge quality assessment methodology to remove toxic content generated by AIGC tools and examine knowledge accuracy.

Subtask c. Developing knowledge filters for removing toxic content. Rules will be designed based on university education policies to filter out toxic descriptions (e.g., profane or discriminatory language), entities, and contents. Semantic analysis conducted by experts will be used to randomly sample AI-generated content to remove inappropriate tones and offensive language. Additionally, human feedback and reviews on AI-generated content will be incorporated to dynamically track content toxicity. The PI Liu has conducted research on human performance assessment in human-robot/AI interaction in the form of questionnaires and task performance (Pang et al., 2021; Huang et al., 2021). The related experience will be used for this project. Based on the assessments, filters will be optimized or redesigned to ensure the generated content is non-toxic.

Subtask d. Assessing knowledge correctness through logic, rationale, and opinion analysis, ensuring reasonable, accurate, and effective knowledge delivery. Existing AIGC tools can generate tons of knowledge, which can contain conflicting and confusing content. Confusing logic in the content will prevent students from digesting the knowledge, and extreme views will hinder both inclusive learning and critical thinking. Therefore AI-generated content must be coherent, consistent, and scientifically sound to help students build their knowledge systems. We will develop several analytic methods to assess knowledge correctness and remove incorrect knowledge. First, the logic analysis will assess the logical consistency and validity of the AI-generated knowledge. The second, rational analysis will be performed using random human subjective assessments of the generated content, ensuring coherence with scientific principles, physical laws, and course theories. Lastly, students' feedback during AIGC usage will be encouraged to provide insights on AI knowledge generation and content adjustments, ensuring the knowledge delivered by AIGC is relevant, accurate, and effective.

<u>Outcome</u>: Non-toxic and logically accurate knowledge will be delivered from AICG to students; effective communication will be established among students to alleviate knowledge barriers among interdisciplinary students.

1.2.3. Research Project 2: Using graphics-based AIGC to address bias and belonging issues in Interdisciplinary Teams

Background and Motivation: Belonging can be referred to as the sense of being connected to or mattering to a group or organization. Belonging has been found to have a significant impact on both graduate and undergraduate education (Gummadam et al., 2016). It is also a critical component of being connected to interdisciplinary teams in STEM (Pluchino et al., 2019). There is evidence that addressing belonging can positively impact all students, particularly minority students (O'Meara et al., 2017). Moreover, getting more females involved in STEM can actually increase interdisciplinarity (Pinheiro et al., 2022). Failing to address such issues of belonging, however, can specifically negatively target women and minorities in STEM (Fisher et al., 2019; Kilty & Burrows, 2022; Stachl & Baranger, 2020). Complicating this issue is the construct of bias. On one hand, interdisciplinary research can reduce bias (Smaldino & O'Connor, 2022). This can be personal bias (e.g., racial; Perdomo et al., 2019) or research bias (e.g., biases in ethical reasoning; Dupras et al., 2020). However, bias towards other researchers or other fields can also reduce the ability for teams to work together in interdisciplinary ways (Fontana et al., 2022). Again, this disproportionately affects females (Russell, 2022) and minority graduate students (Asplund & Welle, 2018). In addition, addressing bias and belonging issues in interdisciplinary teams will improve the overall quality of the team and dynamics that directly enhance team communication and collaboration (Van Dijk, et al., 2017).

In short, there is a complex relationship between success in interdisciplinary teams, hidden or known biases, and a sense of belonging. While working in interdisciplinary teams can positively impact belonging and future work, biases and a lost sense of belonging (also impacted by biases) can negatively impact a willingness to participate in such teams. Various projects have attempted to address each of these issues individually, with working on some of these components in tandem (e.g., Asplund & Welle, 2018; Moss-Racusin et al., 2018). Two of the biggest challenges, however, are uncovering hidden biases and providing models for underrepresented groups so that they can feel like they belong (e.g., Packard, 2015).

AI, and particularly AIGC tools that foster image generation from text, promote two things. First, they provide an opportunity for the creation of images that can potentially uncover hidden biases (Srinivasan & Chander, 2021). Much of this work has been done in healthcare (e.g., Cirillo et al., 2020; Parikh et al., 2019). However, there is some early evidence of its potential for addressing bias in STEM (Riep & Prabhakar, 2021). Second, they provide an opportunity for discussion around such images, which can foster a sense of belonging in working in interdisciplinary teams (Ambrose, 2017; Ferdig et al., 2023; Maher et al., 2022). The purpose of this second research study is to examine if and how AI-generated images can reduce bias and foster a sense of belonging in interdisciplinary STEM teams.

Method: STEM students will be involved in a series of activities whose objective will be to create and then discuss image-based AIGC tools to reduce bias, increase a sense of belonging toward STEM and related workforces, and therefore support collaboration. The research project is planned to rely on longitudinal data collections with which we will evaluate collaborative skills, related performance, and sense of belonging toward STEM workforce before, during, and after the proposed interventions. Two consequential types of studies will be directed to reach this goal.

Research question 2.1 (RQ2.1): How can we use graphic-based AIGC tools to detect hidden biases and promote sense of belonging toward STEM workforce (learners as consumers)?

For answering this first research question, we will provide learners with AI-generated images and prompts to inform different representations of practice (e.g., an underrepresented scientist) (e.g., Singer et al., 2020). First, we will collect recruited students' perceptions and viewpoints on STEM roles, workforce, and sense of belonging (e.g., describe how a scientist looks like). Second, we will generate AIGC images from their replies to develop a visual library of what students think and perceive about STEM work and related interdisciplinary requirements. Third, students will be grouped into interdisciplinary teams (composed of five-six members each) which will be tasked to complete a project (e.g., design a hypothetical mobile application, solve a societal problem like a pandemic) in three months. The projects will be related to real-life challenges and their group efforts will be structured following a standard design cycle (inspiration, ideation, implementation) (Oliveira et al., 2021) and the SCRUM methodology (Morandini et al., 2021). We will supervise each group with weekly meetings by following SCRUM criteria (i.e., iterative design) and deploying AI-generated images as follows: a) each week, students will reply to the same prompts asked in step 1 — this will allow to update the visual library mentioned above and track possible changes; b) each week, we will use these images to help groups in reflecting on their own interdisciplinary efforts, possible group misunderstanding and conflicts, and sense of belonging toward their own field(s).

To summarize, we will generate AI images that would expand STEM representations, detect biases, and visualize constructs like belonging, interdisciplinary collaboration, coordination, teamwork, and STEM disciplines that are different than their own. Students' viewpoints on the matter will work as the baseline to develop a more targeted imaginary. The main objective is to shed light on hidden bias and develop models for underrepresented groups to improve and support sense of belonging (e.g., Packard, 2015). This study will last 3 months and it will be repeated twice with two different groups of students.

<u>Outcomes</u>: improved sense of belonging toward STEM workforce; improved group performances; improved instructional practices in using AIGC images to support students' collaboration, improved understanding of hidden biases in STEM representation.

Research question 2.2 (RQ2.2): How can we make students active producers and creators of graphics-based AIGC tools to support collaboration in interdisciplinary teams (learners as producers)?

This second array of tasks will have students playing an active role in generative AI content. The research design will partially follow the one proposed to answer RQ2.1 – i.e., participants will reply to sense of belonging related prompts and work in interdisciplinary teams on concrete deliverables. However, students will be also asked to use AIGC tools to develop, edit and share their own images with their teams. Therefore, they will deploy their own AI-generated images to drive their own teamwork and collaboration under our supervision. This active participation is designed to support a student-centered approach (Ali, 2019) and empower learners in using this technology as main actors together with their peers. As a consequence, this study will focus on if and how this active involvement may benefit sense of belonging toward STEM and what challenges may occur in switching from learners as consumers to learners as producers. This study will last 3 months, and it will be repeated twice with two different groups of students (not involved with the RQ2.1 study).

<u>Outcomes:</u> improved sense of belonging toward STEM workforce; improved group performances; improved instructional practices in having students generating AIGC images to support students' collaboration, improved understanding of hidden biases in STEM representation; improved understanding of the benefits of having students creating content rather than consuming it.

To summarize, students will be consumers first and then producers of AI content. In both, AI content will serve as an instrument to allow learners to reflect on their sense of belonging to STEM (e.g., Abrica et al., 2020) while being exposed to challenges related to interdisciplinary teamwork and exchanges. This will allow instructors to develop a better understanding of how AI can become a tool to assist students individually and then interdisciplinary teams consequently.

1.3. Intervention: Student Training and Interdisciplinary Team Project

<u>Objective</u>: The intervention aims to help graduate students address communication issues in interdisciplinary teams using customized AIGC tools to improve group collaboration performance.

<u>Method</u>: The project will incorporate the findings from research projects 1 and 2 and develop three training modules for students on how to customize AIGC tool with their respective domain knowledge,

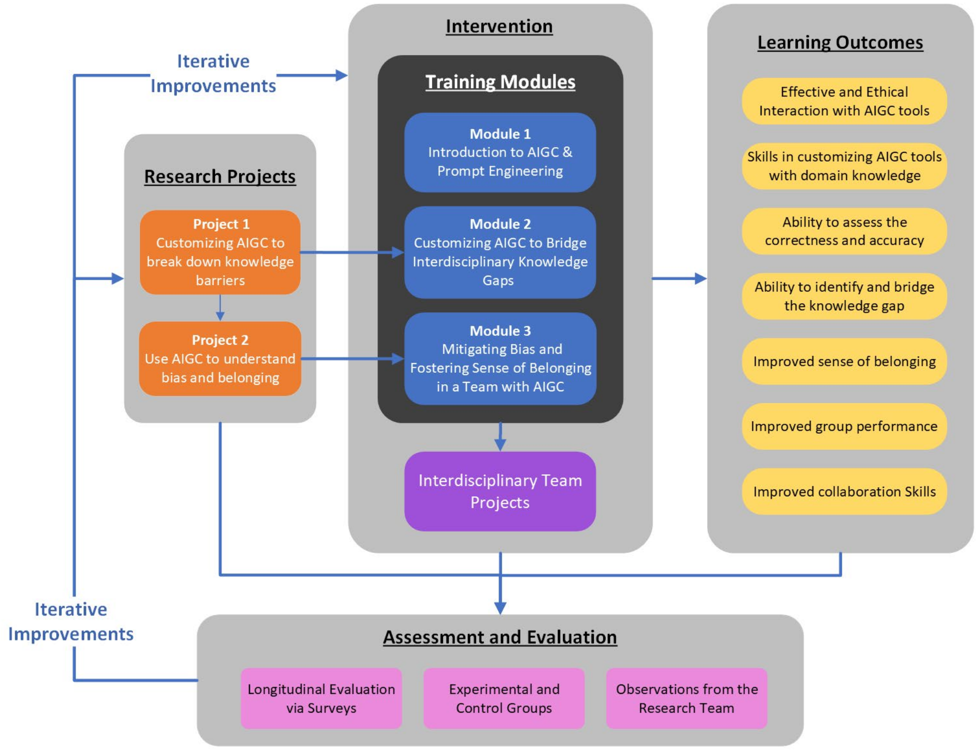


Figure 2. Training and Evaluation

effectively utilizing the tool, and mitigating bias while fostering a sense of belonging in interdisciplinary teams. After completing the training modules, students will participate in an interdisciplinary team project to apply their learning, through which we can evaluate the effectiveness of the proposed research. The project will undergo three rounds of pilot testing, with each round assessed for the student learning outcomes and for iterative improvement of the research methods and training modules. Once the three-round pilot testing is complete, the training modules will be integrated into existing courses and programs in the College of Aeronautics and Engineering and the College of Education, Health and Human Services.

Outcome: Upon completion of the training activities, students will be equipped with complementary skills to better understand logic, jargon, and languages from other fields, exhibit less bias, and will have an increased sense of belonging in interdisciplinary teams, thus fostering a culture that actively seeks conflict solutions. The training will ultimately prepare students as the next generation of researchers and innovators with interdisciplinary team skills and knowledge to tackle complex real-world problems.

1.3.1. Student Training Modules

Module 1. Introduction to AIGC and Prompt Engineering (5 hours)

Description. This module provides an introduction to AIGC tools and prompt engineering, with hands-on exercises for effective and ethical interaction with AIGC tools. AIGC tools use artificial intelligence to create various types of content, while prompt engineering refers to the process of designing prompts that guide AI-generated content generation.

The module will cover the basics of AIGC, including its benefits and potential drawbacks, and introduce different types of AIGC tools, such as ChatGPT, NotionAI, and Midjourney. It will also explore how prompt engineering can be used to guide the output of these tools and ensure that the content meets specific goals and criteria. The module will include hands-on exercises for interacting with AIGC tools, including selecting the right tool for the task, providing quality input data, and testing and refining the output.

Learners will also practice ethical considerations, such as ensuring transparency and accountability in the use of AI-generated content.

Learning Outcome. Upon completion of this module, learners will have gained practical skills in interacting effectively and ethically with AIGC tools and prompt engineering. They will have a solid understanding of how AIGC tools and prompt engineering can be used to create high-quality content efficiently and effectively, as well as be aware of the potential risks and limitations of using AIGC.

<u>Module 2. Customizing AIGC to Bridge Interdisciplinary Knowledge Gaps (5 hours)</u>

Description. This module builds on the knowledge gained in research project 1. The module will integrate the research findings from research project 1 and provide learners with practical skills for customizing AIGC tools to generate a hierarchical knowledge structure that meets specific goals and criteria.

The module will cover the process of customizing AIGC tools, including how to incorporate domain knowledge into the tool's algorithms and input data, how to assess the correctness of the generated content, how to examine the logical correctness of the output, and how to design and implement the filter to avoid toxic output. The module will also teach students how to use the customized AIGC tools to fill knowledge gaps between interdisciplinary team members. By leveraging the customized AIGC tools, learners will be able to generate high-quality content that meets the needs of specific audiences and domains.

Learning Outcome: Upon completion of this module, learners will have gained practical skills in customizing AIGC tools with domain knowledge, ensuring the correctness and accuracy of the output, and using the customized tools to fill knowledge gaps between interdisciplinary team members.

<u>Module 3. Mitigating Bias and Fostering Sense of Belonging in a Team with AIGC (5 hours)</u>

Description. This module is developed by following research project 2's findings. Therefore, it will focus on how graphic-based AIGC can be harnessed to support students in reflecting on their academic progress, visualizing their own emotions and feelings in the context of STEM education, and promoting the sense of belonging and attachment toward the disciplines covered by this proposal.

In order to achieve these objectives, the module will cover three core areas. First, it will provide an overview of which tools can be used and related features, limitations, and best practices (e.g., type of prompt, filters). Second, it will address leading pedagogies and instructional strategies to implement this knowledge in interdisciplinary settings, from education to work settings. Third, it will explore how soft skills, from collaboration to self-efficacy and the sense of belonging, can be promoted through this technology.

Learning outcome: the learning outcome of this module is to train students in mastering graphic-based AIGC software to self-growth and group development. After this module, learners will be able to apply AI-generated images to promote diversity and inclusion toward themselves, their colleagues, and also their own students across different disciplines and backgrounds.

1.3.2.Interdisciplinary Team Project

In order to assess the impact of the intervention and evaluate its effectiveness, a demonstrative interdisciplinary team project will be conducted, involving two distinct groups of graduate students: (1) a control group, consisting of students who have not participated in the training modules, and (2) an experimental group, comprising students who have completed the training modules. While there are many factors that affect the quality of interdisciplinary teamwork (Nancarrow et al., 2013), in this project, we will limit the variables and focus our attention specifically on team communications. The primary objectives of these team projects are (1) to evaluate the extent to which the training intervention has successfully achieved the desired learning outcomes outlined in the training modules, and (2) to provide students with hands-on practice of the skills learned in the training modules. The team activities will be designed as interdisciplinary exercises, tailored to suit the student population participating in the specific activity session. Owing to the limited time available, these projects will be constrained in scope, yet will closely resemble typical interdisciplinary projects commonly encountered in both the workforce and research/academia.

During the course of their project, students in the experimental group will be explicitly instructed to utilize the AIGC tools to facilitate their technical communications, encompassing both intra-team communication and team presentations. Conversely, while students in the control group will have access to the AIGC tools, they will not be specifically mandated to use them and may elect to do so at their own discretion. Throughout the project, both groups of students will be expected to fulfill the following requirements: document the interdisciplinary group process; compose a group paper detailing the team's findings on their chosen topic; deliver a public presentation; and assess their peer team members' participation throughout the project's duration. The exact project details will vary depending on the specific student group, two illustrative examples are provided below for context and structure.

Example Interdisciplinary Project 1

In this project, we assume a population of graduate students from Aerospace Engineering, Mechatronics Engineering, Cybersecurity Engineering, and Education Technology. A tentative project title is to Design a Robotic Kit as a Personalized Learning Device for STEM Students (Ruzzenente et al., 2012; Yu et al., 2001). Graduate students from Aerospace Engineering and Mechatronics Engineering combined have the key skills needed to design such a system whereas Cybersecurity Engineering students can address the software/network issues of implementing such a system and Education Technology students have the knowledge and experiences to know the key issues and design considerations for such a technology. All in all, through this project, the students will be interacting within the context of an interdisciplinary team where they need to work together to come up with a design. There are several tasks and milestones that the students have to accomplish: (1) identify the specific issues that the team would like to address in STEM education, (2) come up with design requirements for the Robotic Kit, (3) identify and design the key components of the Robotic Kit including hardware (i.e., sensors and actuators), and software, (4) assemble and integrate the robotic kit and provide a demonstration.

Example Interdisciplinary Project 2

In this example project, we assume a population of graduate students from Aerospace Engineering, Mechatronics Engineering, and Cybersecurity Engineering. A tentative project title is Designing a Secure Communication and Control System for a Quadcopter, where the teams will design, develop, and evaluate a Secure Communication and Control System for a commercial off-the-shelf (COTS) quadcopter (Tang 2021; Jordan et al., 2022) that can improve the security and reliability of a readily available quadcopter for applications, such as aerial photography. The aerospace engineering students will focus on selecting a suitable COTS quadcopter and analyzing its flight performance, control systems, and payload capabilities. They will also collaborate with the mechatronics and cybersecurity engineering students to integrate the secure communication and control system. The mechatronics engineering students will be responsible for designing and implementing the control algorithms required for the quadcopter's stability and maneuverability. They will also work on creating an intuitive user interface for operators to control and monitor the quadcopter's activities in real time; while the cybersecurity engineering students will focus on developing a secure communication protocol for the control and telemetry data between the quadcopter and the ground control station. They will implement encryption and authentication mechanisms to protect communication from unauthorized access and hacking.

Outcome Assessment and Evaluation

During each project session, two groups (one control and one experiment) will carry out the same project in parallel with equivalent team members and expertise. While each student will have different experiences and backgrounds, ending in different project results, the key aspect of the team projects is to evaluate their respective intra-team and external communication skills throughout the team project. The evaluation will be conducted from both the perspectives of the students and the project research team. Quantitative and qualitative surveys will be used to assess the overall communication skills of participants throughout the project. A detailed assessment plan is outlined in Section 3.

1.4. Targeted Graduate Student Population

The project targets STEM graduate students from Kent State University. The first group consists of graduate students from the College of Aeronautics and Engineering (CAE) who major in Aerospace Engineering – M.S. & Ph.D., Mechatronics Engineering – M.S. & Ph.D., and Engineering Technology – M.E.T, and the second group is the graduate students from the College of Education, Health and Human Services (EHHS) who major in Educational Technology (M.Ed., Ed.D., Ph.D.).

The selection is based on two factors. Firstly, these disciplines often require collaboration between individuals from different fields and backgrounds, making interdisciplinary communication skills essential for success. Secondly, these students often encounter complex technical problems that require interdisciplinary teamwork to solve, which necessitates effective communication skills. The first group of graduate students from the CAE is chosen because they are part of a highly technical field where collaboration is critical. The aerospace industry, for example, requires individuals from various fields to work together to design and develop new technologies. Similarly, mechatronics engineering involves the integration of mechanical, electrical, and computer engineering fields. Therefore, interdisciplinary communication skills are essential to achieving success in these fields.

The second group of graduate students from the EHHS is included because technology is rapidly changing the field of education, and the ability to communicate effectively across disciplines is essential. Graduates in this field will be tasked with using technology to enhance the learning experience of students from various disciplines. Therefore, they must be able to communicate effectively with individuals from different fields to ensure that their technological solutions meet the needs of all learners.

1.5. Institutional Plans

<u>Facilitation of the Pilot</u>

The project will offer three rounds of pilot training in the College of Aeronautics and Engineering (CAE) at Kent State University. The 4-month pilot training will take place during the Spring 2025, Fall 2025, and Spring 2026 semesters, respectively. The training will be conducted in the CAE's CyberRange computer lab during set times in each semester. The Co-PI Dr. Stringer is the Graduate Program Coordinator and will facilitate the training process. Dr. Chen, Dr. Gandolfi, and Dr. Koptur, will develop and deliver the training modules. Dr. Lu will lead the interdisciplinary team projects, and the PI team will also work with graduate faculty and student research advisors to provide incentives and/or availability for graduate students to participate in the module training and interdisciplinary team projects. Dr. Harrison is the Associate Dean of Research & Faculty Affairs in the CAE and will coordinate with other faculty and administrators in the college and the university to ensure smooth project progress. The CAE will also provide support for project activities that may require the use of college facilities, equipment, and other resources. Additionally, the PI team will work with the College Graduate Office to disseminate the availability of these pilot training opportunities to the widest audience possible.

<u>Dissemination</u>

During the course of the project, data will be gathered, analyzed, and prepared for dissemination in various forms. Firstly, the outcomes will be shared with faculty and staff in CAE and EHHS to encourage their adoption of the training modules in their courses. Secondly, the project results and findings will be presented at conferences at the state, national, and international levels, which attract educators, career counselors, and higher education personnel. Some targeted conferences include, but are not limited to, those hosted by American Educational Research Association (AERA) Annual Meeting, American Counseling Association (ACA), The National Career Development Association (NCDA), and Higher

Education focused associations like NASPA-Student Affairs Administrators in Higher Education and American College Personnel Association as well as the American Society for Engineering Education (ASEE), and Association for Technology Management and Engineering (ATMAE). Finally, manuscripts that were derived from the acquired data will be submitted to journals that cater to education, career, and counseling-related professionals, as well as peer-reviewed journals in STEM-related academic disciplines. The objective is to disseminate the findings broadly, expand knowledge in the field, and contribute to the existing literature. Moreover, the final improved training resources will be hosted on a publicly available Open Educational Resource site, to expand access and foster widespread adoption by educators and learners globally.

Course and Program Integration

The proposed training modules aim to enrich various aspects of the current degree programs, focusing on enhancing skills, practices, theoretical knowledge, AI awareness, and interactions among interdisciplinary team members. The strategic plan for course enrichment includes the following components:

- Skills enhancement: The training modules can improve student'' interdisciplinary collaboration skills and problem-solving abilities. These enhancements will enable students to work more effectively with team members from different backgrounds and contribute to successful project outcomes.
- Practices improvement: By integrating practical, hands-on, and real-world case studies in interdisciplinary team projects, the training modules will help students develop a deeper understanding of the challenges and opportunities in interdisciplinary collaboration. This practical focus will foster the application of newly acquired skills and knowledge to real-world projects.
- Theoretical knowledge expansion: The training modules will provide students with a solid theoretical foundation in interdisciplinary collaboration, drawing from relevant research and theories in the field. This knowledge base will support students in developing a more nuanced understanding of the complexities involved in working across disciplines.
- AI awareness: The training modules will include discussions and demonstrations of AI-generated content and its potential impact on interdisciplinary collaboration. This focus will help students recognize the potential benefits and challenges associated with AI applications in their respective fields.
- Interaction enhancement: The training modules will promote active learning through group activities, discussions, and peer feedback. These interactive elements will foster a collaborative learning environment, encouraging students to engage with their peers and learn from diverse perspectives.

To achieve these goals, the three training modules will be integrated into existing courses, particularly those that involve interdisciplinary collaboration or have a strong emphasis on teamwork and project-based learning. This includes graduate engineering courses, such as ENGR 57200 Systems Engineering, ENGR 65250 Human Factors Engineering, and ENGR 61091 Graduate Seminar courses that cater to an interdisciplinary student audience. The course and program integrations are described in detail below. By strategically enhancing these aspects and integrating the proposed modules, the training modules will provide meaningful added value to the current degree programs, preparing students for success in an increasingly interdisciplinary and technologically driven world.

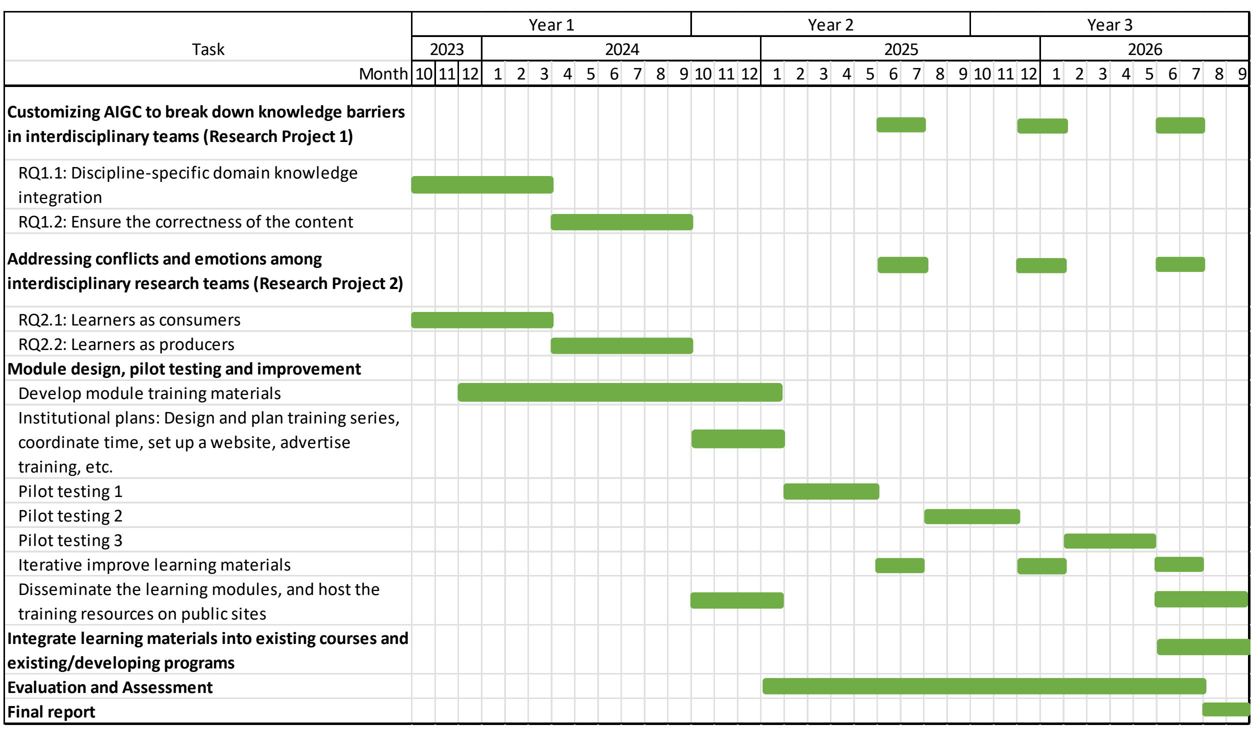
Course Integration. There are three potential graduate engineering course integrations for these modules in the current course catalog of the College of Aeronautics & Engineering. They are ENGR 57200 Systems Engineering, ENGR 65250 Human Factors Engineering, and ENGR 61091 Graduate Seminar. These course integrations are particularly appropriate for a few reasons. Systems Engineering requires a macro-optic view of an entire system and how different teams and disciplines must work together to completely engineer a complex system (e.g., a skyscraper, boat, power plant, aircraft, etc.). Human Factors (HF) is appropriate because it includes topics on the influence of the physical and social environment on human perception and performance in various contexts. Furthermore, HF engineering is a design consideration for every system, requiring HF engineers to work on projects of very different complexities and disciplines, where AIGC tools can greatly enhance the interdisciplinary knowledge of the team. Graduate seminar course perhaps offers the best ability to reach new multi-disciplinary students, as it is required for master's and doctoral research engineering students, which can then filter into their other coursework.

Interdisciplinary team research project. This project includes a comparison of pre-and post-module implementation. Pre-module implementation can best be assessed via first-year students in the Fall offering of ENGR 61091 Graduate Seminar. Post-module implementation occurs in either ENGR 57200 Systems Engineering or ENGR 65250 Human Factors Engineering. This provides a sample comparison to evaluate the outcomes of the project.

Program Integration. Upon successful completion and refinement of the modules in Year 3, they will be integrated into the graduate engineering programs of the College of Aeronautics & Engineering, via the courses mentioned above. Currently, the college offers a Master of Engineering Technology (professional degree), and master's/doctoral programs in aerospace engineering and mechatronics engineering. At the end of Year 3, we anticipate offering a master's/doctoral program in cybersecurity engineering as well. Either ENGR 57200 Systems Engineering or ENGR 61091 Graduate Seminar or both are required courses in all of these graduate programs. This deliberately targets both professionally oriented (non-thesis) students and research student populations by integrating the modules in these courses. In Educational Technology (M.Ed.), three courses will be considered as a potential focus of integration, ETEC 47400-57400 Trends in Educational Technology, ETEC 67434-77434 Emerging Technologies for Education, and ETEC 67432-77432 Designing Multimedia for Education. All three courses have an interdisciplinary student audience, from computer science and education to communication and public health. As such, they will represent an ideal outlet to test interdisciplinary efforts in the context of STEM education, learning, and workforce development.

1.6. Project Timeline

Table 1 Project Execution Plan



The project will span three years, as outlined in Table 1. In the first year, two research projects will be undertaken, and training materials will be developed. Then in year 2 and year 3, the PI team will conduct the three rounds of the 4-month pilot, comprising a 2-month module training and a 2-month interdisciplinary team project. Each round of pilot will be accompanied by evaluation and assessment, followed by improvement of the methods of two research projects and the improvement of the training materials. Throughout year 2 and year 3, the training materials and research findings will be disseminated in conferences and journals and finally, the training will be integrated into existing courses and programs.

2. Broader Impacts

2.1. Advancing STEM Education

Graduate students with such interdisciplinary training have broader perspectives on complex problem analyses (including capabilities with new insights and innovative solutions), enhanced creativity from digesting other disciplinary approaches, improved communication skills with an understanding of other fields of logic, jargon, and languages from other fields, expanded networks with diverse collaborators and developmental opportunities, and transferable skills with critical thinking and adaptability in knowledge exchange and implementation. These interdisciplinary qualities will help students become more effective researchers and innovators.

The modules developed in this project can be extended to other institutions nationally and internationally, as outlined in the dissemination plan. It will innovate graduate education in engineering and education, while also having far-reaching influences in other STEM fields. In addition, the specific training modules could potentially advance educational efforts at decreasing bias and increasing a sense of belonging for STEM graduate students.

2.2. Competitive STEM Workforce and Increased Economic Competitiveness

There are inherent impacts of this project that transcend the classroom, many with the potential to transform society and the way teams in professions operate. This project will directly contribute to the development of the STEM workforce by educating STEM graduate students with the core capabilities of communication while working in interdisciplinary teams. In addition, as AIGC tools will reshape the landscape of the future of work, equipping the students with the knowledge and skills of using AIGC will greatly improve the quality of the workforce.

Assuming that many graduate students see graduate work as a means of acquiring additional knowledge and skills to move upward in their professions, the learning that results from these activities can move into company boardrooms and project team meetings, enhancing communication, decision-making, and inclusivity. Furthermore, this work has the potential to transform the current perception of Artificial Intelligence both in academia and in the public into a beneficial tool that enhances human productivity rather than replaces it. From a STEM perspective, this education innovation with AIGC ultimately has the potential to transform technologies themselves by producing professionals who will develop products or services that were specifically designed with diversity in mind to maximize their benefits to all of society.

2.3. Inclusion and Broadening Participation

In bringing together different student populations from multiple disciplines and training them in these modules, traditional graduate programs may evolve into multi-professional programs, providing (1) a means of developing a common language with common standards between different domains, (2) exposure to broader fields in the context of their relationship to one's primary discipline, and (3) the integration of these different perspectives, providing a more inclusive appreciation of a discipline's role and relevance in society.

Artificial intelligence platforms have the potential to provide commonality, breadth, and inclusivity to graduate education programs in several ways. Commonality refers to the way in which AICG tools can provide a common learning experience for students. AI platforms also offer a wider breadth of learning scenarios, activities, and learning opportunities than traditional classroom-based education. Finally, team members from underrepresented groups in STEM, participants with disabilities, those who live in remote areas, or team members who have family or work commitments that prevent them from personal interaction, can use these platforms to enhance their communication and visibility with the team and enhance the results of interdisciplinary collaboration efforts.

3. Performance Assessment/Project Evaluation

The project evaluation and assessment will rely on two main formative assessment cycles (year 2 and year 3) and a summative one at the end of project timeline.

The two formative assessments cycles will be structured as bi-monthly meetings with the whole project team to evaluate the following three parameters: (1) task completion: the team will assess which planned tasks have been executed and detect criticalities to consider; (2) iterative design: the team will reflect on issues and challenges that emerged in the project in order to address them timely; and (3) technology adjustment: the team will discuss if and how AIGC tools deployed should be changed or revised to improve project's outcomes and deliverables.

The summative evaluation will be directed by the whole team by addressing (1) the suggested learning outcomes (see Figure 2) and related achievements, (2) the concrete broader impact of the project (e.g., involvement of other institutions, increased diversity in our student population), (3) areas of future research and development. At the end of each formative assessment cycles and of the summative assessment a report will be produced with main evaluation's findings.

In order to support these endeavors, the project evaluation will cover a) the two research projects, b) student training modules; and c) interdisciplinary team projects.

<u>The research projects evaluation</u> will rely on (1) a longitudinal evaluation (pre, mid, post) via surveys and (2) experimental (being exposed to the planned AIGC intervention) and control (being exposed to non-AIGC informational content – e.g., articles and videos about interdisciplinary work in STEM) conditions. The following constructs will be measured at the beginning, during, and at the end of the research projects' activity.

- Academic performance. Criteria such as "student engagement time, learning outcome, academic performance, comfort with learning, research progress, communication efficiency." will be established to assess student learning outcomes and the effectiveness of the proposed content filters;
- Student engagement will be assessed using the higher education student engagement scale (HESES) (Zhoc et al., 2019). Evaluation methods may include both subjective and objective approaches, such as questionnaires and quantitative academic performance indicators. Measurements will encompass peer evaluation, self-assessment, observation, and surveys, facilitating peer-to-peer assessment, self-identification of engagement quality, observation of interactions and contributions, and data collection on satisfaction and collaboration quality.
- Collaborative thinking will be measured using the Collaborative Learning Scale (CLS) proposed by Loes & Pascarella (2017). The CLS assesses three dimensions of collaborative learning: perceived individual participation, perceived quality of interaction, and perceived learning outcomes.
- Correctness assessment. Students will be encouraged to provide feedback on AI-generated knowledge and content adjustments, ensuring the relevance, accuracy, and effectiveness of the knowledge delivered by AIGC in helping them build their knowledge systems. Based on the assessments, corrections and adjustments will be made to filters, prompts, and assessment methods to ensure the high-quality delivery of AI-generated knowledge.
- Sense of belonging via the sense of belonging instrument (SOBI) (Hagerty & Patusky, 1995). SOBI was developed by Hagerty and Patusky (1995) to measure a participant's sense of belonging. It measures two specific factors: the SOBI-P includes 18 items and measures the psychological experience of sense of belonging; the SOBI-A includes 9 items and measures antecedents to sense of belonging and the motivation and willing to belong. SOBI will be revised with an emphasis on STEM workforce for the purposes of the project

For both research projects, an artifact analysis (Trausan-Matu & Slotta, 2021) will be also directed toward the outputs of the student groups involved. Moreover, participants will be observed and evaluated by following the Collaborative-Computing Observation Instrument (C-COI) (Israel et al., 2017). Participants' demographics (age, gender, race/ethnicity, academic standing, major) and feedback (e.g., notes about AIGC tools and related features) will be gathered to detect associations that can help detect biases and personalize instruction.

The student training modules' evaluation will rely on the same methodology to evaluate their outcomes. Students will be split into experimental and control groups, and they will be measured by deploying the same constructs at three data entry points. However, this assessment will follow a different timeline. Students will be evaluated before the module, after the module, and at the end of the course embedding the module. This will facilitate a better understanding of the long-term effects of AIGC interventions. In addition, focus groups with the instructors will be directed after module delivery to gather strengths, limitations, and areas of improvement regarding this type of intervention.

The interdisciplinary team projects will be evaluated against four main rubrics: (1) quality of collaboration and communication among team members, (2) problem-solving and decision-making abilities, (3) achievement of project milestones and objectives, and (4) ability in addressing unforeseen challenges. While the first criterion is directly tied to the learning outcomes of the training module, the other three criteria will help the research team to understand the overall success of the team project which is an indirect assessment of the quality of the team dynamics. Specific assessments will include (1) self-assessment questionnaires for team members, (2) peer assessment questionnaires to gather feedback on each team member, (3) team progress report detailing milestone achievement, and (4) observations and assessment of team meetings and communications exchanges. The first three modes of assessments are done by the student participants while the last (#4) will be conducted by the research team of this proposal.

4. Results from Prior NSF Support

Gandolfi (Co-PI) and Ferdig (key personnel) were funded in 2019 by an NSF DRK-12 project (#1908149; 9/1/19-8/31/22) called "Design and Implementation of Immersive Representations of Practice." The project sets out to explore the use of 360 video to improve teacher noticing as well as tacit and explicit knowledge for teaching mathematics. This project has generated over 20 journal articles and several book chapters and conference proceedings as reported on the project's official website. While the content of that project is not directly related to this proposal, the prior funded grant does use artificial intelligence and machine learning to attempt to predict if, when, and where teacher noticing happens in the classroom. Gandolfi and Ferdig will use learnings from that project to inform the AI work in this proposed work.

- Intellectual Merit: the aforementioned project aimed at exploring the use of immersive videos and related technologies (360 videos, eye tracking, machine learning) to support and enchance teacher education in STEM. Therefore, it has provided theoretical and practical insights to deploy this innovation for learning in higher instruction.
- Broader Impacts: the project's products and implications have been noteworthy for a wide range of disciplines and stakeholders. A platform has been created and made accessible at not cost with immersive videos for instructional purposes and informational content to guide and support teacher educators from any background in using 360 videos in their instructional practices.
- The publication resulting from this award is listed in the References Cited section of the proposal.
- Other products: Representations of Mathematics Teaching & Learning: 360 Video of various classroom teaching scenarios (YouTube links are in the References Cited section).