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Interdisciplinary and Project-Based Service Learning for Smart and Connected Communities: Insights from ENDEAVR

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ABSTRACT

Higher education institutions are increasingly interested in innovative pedagogies that offer hands-on, project-based learning experiences in interdisciplinary settings and enable students to address real-world challenges with emerging technologies. To address this demand, a team of educators, in collaboration with community and industry partners, created an interdisciplinary and project-based service-learning program named ***E****nvisioning the* ***N****eo-traditional* ***D****evelopment by* ***E****mbracing the* ***A****utonomous* ***V****ehicles* ***R****ealm (ENDEAVR). The team piloted the program during the 2019-2020 academic year. Program evaluation was conducted using both pre-post surveys and focus groups centered on the program's impact on students' critical thinking and problem-solving skills. This article summarizes key lessons, challenges and experiences from the pilot program, and shares insights on curriculum design and program implementation.*

Keywords: community-driven innovation, higher education, Interdisciplinary, project-based, service-learning, smart cities

INTRODUCTION

Over the past decade, demands and practices of interdisciplinary, project-based, service-learning in higher education institutions have been rapidly increasing (Balassiano, 2011; Chen et al., 2020; Johnston, 2014; Levkoe et al., 2018; Neuman, 2016). Interdisciplinary approaches to teaching and learning help students think critically and holistically, adapt to a multidisciplinary workplace, and solve complex problems (Klein & Newell, 1997; Repko et al., 2019). Project-based courses are powerful in improving students' problem solving and critical thinking skills (Balassiano & West, 2012). Service-learning brings mutual benefits to students and communities. It benefits students cognitively by enhancing their sense of social responsibility and individual efficacy while generating practical outputs helpful in addressing some of the pressing issues facing the participating communities (Bowman et al., 2010; Levkoe et al., 2018).

Educators and researchers are exploring strategies to better prepare post-secondary students to respond to the rapid technological transformation (Collins & Halverson, 2018). Addressing this requires pedagogical approaches crossing programmatic boundaries to engage a wider range of disciplines as a means to provide students with more transformational learning experiences involving future urban technologies and developments. Although some existing interdisciplinary courses focus on urban environmental theories and methods (Balassiano & West, 2012; Chen et al., 2020; Johnston, 2014; Yocom et al., 2012), they involve students from urban planning, urban design, landscape architecture, and architecture, whose disciplines share significant commonalities. Further, existing courses do not engage the full disciplinary range needed to address the emerging challenges associated with technological transportation. Such emerging challenges require students to explore, propose, and implement novel "smart" solutions for communities.

Additionally, considerable misalignment exists between higher education institutions' curricula and communities' emerging technological needs (Grimaldi & Fernandez, 2017). Such misalignment compromises undergraduate students' training and preparation to harness the power of technologies to solve real-world problems. Little guidance has been developed for post-secondary educators to educate students in emerging technologies, including awareness, understanding, acceptance, adoption, and deployment of emerging technologies to deliver innovative services for cities and communities (Aranya & Vaidya, 2016; Grimaldi & Fernandez, 2017; Smith, 2017).

To fill gaps in interdisciplinary education programs related to smart and connected communities, a diverse team of educators created an innovative program named **E**nvisioning the **N**eo-traditional **D**evelopment by **E**mbracing the **A**utonomous **V**ehicles **R**ealm (ENDEAVR). The project engages students from various disciplinary backgrounds, including computer science, civil engineering, electrical engineering, landscape architecture, urban planning, and visualization. Co-designed and co-instructed by faculty, community clients, and industry leaders from diverse disciplines, the ENDEAVR program provides students with the opportunity to tackle real-world problems and develop smart solutions.

This paper presents the ENDEAVR program, an innovative and effective higher education approach to interdisciplinary, project-based service learning for addressing emerging challenges associated with smart and connected communities. We summarize ENDEAVR's program development; pilot implementation; and evaluation, including the program's impact on students' critical thinking and problem-solving skills. Also, we recommend the ENDEAVR "Spiral" as a framework to maintain and sustain the program's long-lasting impacts on student learning.

LITERATURE REVIEW

Interdisciplinarity, project-based, and service-oriented are the three theoretical pillars supporting the ENDEAVR program's development.

Interdisciplinarity

Interdisciplinary thinking is a cognitive process by which individuals or groups draw on multiple disciplinary perspectives, integrating their various epistemological insights and modes of thinking to advance their understanding of a complex, authentic, real-world problem with th goal of applying this integrated understanding to proposing a solution (Repko et al., 2019). Interdisciplinary studies have expanded on a widely held belief that our society, workplace, and knowledge have become increasingly interdisciplinary (Klein & Newell, 1997). Because of this, more and more work in this area is being conducted in higher education by educators and researchers to develop and study interdisciplinary approaches to teaching and learning (Chen et al., 2020; Johnston, 2014; Kurland et al., 2010; Yocom et al., 2012). Smit and Tremethick (2013) found that interdisciplinary courses allowed students to expand their understanding of class materials in different disciplines. Jones (2010) stated that interdisciplinary studies can enhance students' communication skills and enrich their lifelong learning habits, and Johnston (2014) further reported additional benefits related to students' collaboration skills.

Interdisciplinary studies, however, pose challenges to students and educators. Students might experience confusion and difficulty when they attempt to integrate knowledge from other disciplines and work with students in other disciplines (Bradbeer, 1999). It is time-consuming for instructors to prepare an interdisciplinary curriculum (Jones, 2010). The existing university system does not have a uniform venue for teaching and learning across disciplines, requiring instructors to creatively develop a variety of mechanisms to support interdisciplinary courses. For example, some faculty have solicited outside companies to sponsor and sustain students' projects (Fixson, 2009). Kurland et al. (2010) reported that having clear and consistent leadership is critical for the success of an interdisciplinary curriculum; effective leadership will decide where to house interdisciplinary activities and clarify student expectations.

Project-Based Learning

Project-based learning is a student-centered pedagogical approach, actively engaging students using authentic, real-world projects (De Graaff & Kolmos, 2007; Stokols, 2018). Students work on projects that interest them, with instructors serving as facilitators and mentors rather than expert lecturers (Frank & Barzilai, 2004; Gülbahar & Tinmaz, 2006). This teaching approach engages students in various types of tasks, allowing the instructor to meet students' diverse learning needs. Many researchers believe project-based learning affords students greater responsibility and motivation for learning (Frank et al., 2003; Krajcik & Blumenfeld, 2006). In addition, tackling complex and real-world problems helps enhance students' communication, collaboration, time management, and decision-making skills (Frank & Barzilai, 2004; Gavin, 2011).

Project-based learning, while proven impactful for student learning, requires much advanced preparation on the instructor's part to ensure meaningful learning. Working on unstructured projects poses many challenges to students. They often report getting confused in the early stages and overloaded with work (Gülbahar & Tinmaz, 2006). To increase effectiveness, it is important for instructors to create a learning community for students and provide students with experiences in self-directed learning and teamwork before or during the process (Frank et al., 2003; Johnston, 2014).

Service Learning

Service learning is a pedagogical approach that combines community-based work with in-class instruction and reflection (McCarthy & Tucker, 2002; Novak et al., 2007). Service-learning has been adopted and implemented in a variety of disciplinary and interdisciplinary courses (Reed et al., 2015; Warren, 2012). These courses often forge meaningful collaborations with governmental entities, nonprofit organizations, and small businesses. The specific projects and outputs vary depending on the partner's needs and the participating students' expertise and capacities. In some instances, students function as consultants by collecting data, conducting analyses, and designing plans (Balassiano & West, 2012). In other instances, students serve as facilitators, providing assistance during events and sessions (McCarthy & Tucker, 2002). Additionally, some students assist partners by creating and delivering digital or physical products (Levkoe et al., 2018).

Novak et al. (2007) and Warren (2012) found participating in service learning benefits students by enhancing their academic understanding of the subject matter, practicing skills, and improving their ability to apply knowledge and reframe complex social issues. Astin et al. (2000) argued serving partners increased students' sense of personal efficacy and responsibility. Reed et al. (2015) reported students who took service-learning courses were more likely to complete their degrees than those who did not. However, Levkoe et al. (2018) pointed out the pitfalls of student-project mismatch, which resulted in the quality and depth of student work not meeting the partner's needs.

RESEARCH QUESTIONS

To contribute to the literature on interdisciplinarity, project-based, and service-oriented learning in higher education, and respond to the increasing demands to implement pedagogies that allow students to use emerging technologies to address real-world challenges, this study aims to answer the following three questions:

1) Development. How was the ENDEAVR program, a higher education interdisciplinary, project-based, service-learning program, developed to address emerging challenges associated with smart and connected communities? [Section The ENDEAVR Program]

2) Impact. Are there differences in ENDEAVR student participants' problem-solving skills and/or critical thinking skills after program participation? [Section Program Evaluation]

3) Reflection. What are the lessons learned and recommendations from the ENDEAVR pilot program? [Section Lessons Learned]

THE ENDEAVR PROGRAM

Overview

The ENDEAVR program was sponsored by the W. M. Keck Foundation and Texas A&M University. During the 2018-2019 academic year, a diverse team of program stakeholders developed an interdisciplinary seminar course; a framework for converting an existing capstone course into an interdisciplinary, project-based, service-learning course; a community outreach plan; and an assessment plan anchored by the courses' student learning outcomes. The ENDEAVR program was piloted in the 2019-2020 academic year. It is designed as an interdisciplinary smart city education platform offering students experiential, hands-on learning across science, technology, engineering, art, and mathematics, the STEAM disciplines. In an academic year, participating ENDEAVR students work directly with community partners to identify problems and initiate new or implement on-going "smart-city" projects.

The ENDEAVR program's design aims to be a scalable and transferable pedagogical approach to promote interdisciplinary, project-based, service-learning in higher education institutions across the nation (ENDEAVR Institute, 2020). By breaking disciplinary boundaries, ENDEAVR students are encouraged to seek creative, affordable, and effective smart city solutions for local communities. In Spring 2020, the ENDEAVR Institute (www.endeavr.city) was established as a nonprofit organization to support the ENDEAVR program's implementation, as well as sustain future activities.

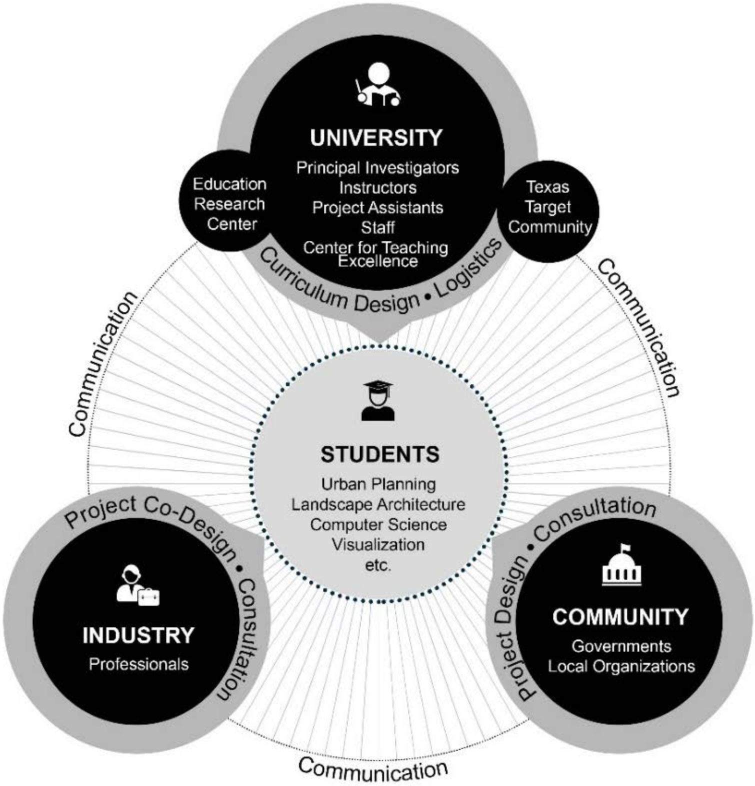
Interdisciplinarity, project-based, and service-learning are the three theoretical pillars supporting the ENDEAVR program's development. An interdisciplinary approach allows students to practice metacognition (Azevedo & Aleven, 2013; Keestra, 2019) as they explore connections between their field of knowledge and other relevant fields. This helps ensure students have a more holistic understanding of the problem before transitioning to the solution phase. A project-based learning approach is student-centered, allowing students to apply their knowledge and skills in a practical context. The project creates a platform to nurture collaboration, critical thinking, and creative problem-solving. A service-learning approach enables students to deliver positive, authentic impact as part of the learning process, potentially allowing for empathy and social responsibility development as well.

The above three pillars are closely related and complement each other. When students are engaged in a specific project as requested by a real-world community client, they encounter authentic challenges that require interdisciplinary approaches to developing solutions. By integrating knowledge from multiple disciplines, students' learning outcomes, particularly critical thinking, and creative problem-solving skills, can be significantly enhanced by collaborating with other team members with diverse interests, abilities, and skills and by developing a deeper understanding of nature of the problems and exploring alternative solutions considering their practical implications.

Leadership Team

Figure 1 shows the ENDEAVR leadership team structure. Faculty and administration teams, industry professionals, and community leaders co-design and co-instruct the ENDEAVR student projects. A team of experts from Texas A&M University's Education Research Center (ERC) independently conducted a research study to evaluate the ENDEAVR program's impact on student participants.

Figure 1: ENDEAVR Leadership Team Structure



The ENDEAVR program is led by principal investigators (PIs) and co-PIs in urban planning, computer science, landscape architecture, and visualization. Besides the program's PIs, course instructors, Texas Target Communities (TTC), project assistants, departmental staff members, and the Center for Teaching Excellence (CTE) also play important roles in the ENDEAVR program's curriculum design and course organization. TTC is a university-wide community engagement program, connecting communities and their needs with an ENDEAVR team in the beginning stage. A faculty and administration team served as project initiators, instructing the ENDEAVR-specific courses, as well as recruiting and maintaining community and industry partner relationships.

Building upon a long-term, mutually beneficial community-university relationship, the city of Nolanville, TX, (Nolanville) has been a critical component of the ENDEAVR team throughout the process. The extensive local network, desire to stay involved, and available capacity made Nolanville's city leadership team an ideal community partner. Team members met periodically with

ENDEAVR faculty and students to share their city's challenges and insights. Topics shared by Nolanville's leaders included transportation, governance, population aging, economic growth, sustainable development, and social inclusion. These discussions led to a summary statement of challenges that directed student projects. During the project development process, community leaders served as advisors for the ENDEAVR student teams.

In Spring 2019, the ENDEAVR leadership team hosted a Tech Summit in College Station, TX. Inspired by the ENDEAVR group's pedagogical vision presented at the Summit, industry leaders—CDM Smith, CityFront Innovation, Plano Intelligence, and Wocsor—joined the team. These industry partners co-designed student projects, organized field trips, and offered training and consultation sessions to students.

Curriculum Structure

The ENDEAVR program's pedagogical approach has two major curricular components: (1) an interdisciplinary seminar course (ISC) taken by participating students in the fall semester and (2) an interdisciplinary project-based learning capstone course (IPBLC) taken in the spring semester. The ISC is a one credit hour course aimed to enhance students' understanding of other disciplines participating in the program, develop teamwork skills, and nurture a culture of interdisciplinary collaboration and learning. The IPBLC is a project-based 'plug-and-play' style pedagogical approach, easily integrated into existing three-to-six credit hour courses. The IPBLC is designed for students to undertake interdisciplinary smart city projects to solve real-world problems. Table 1 lists the key student learning outcomes and the corresponding course activities and deliverables for both the ISC and the IPBLC. Students are strongly encouraged to take ISC prior to IPBLC.

Previous studies report that transferable skills, namely problem solving, critical thinking, time management, collaboration, communication, and creative thinking, are extremely important for students' successful transition into the workplace and should be essential outcomes of higher education (Eisner, 2010; Hill et al., 2019). Interdisciplinary, project-based service-learning is an effective way for undergraduate students to develop these transferable skills (Cahill, 2014; Cargas et al., 2017; De los Ríos-Carmenado et al., 2015; Snyder & Snyder, 2008). Accordingly, student activities include attending seminars, reading assigned materials, conducting team building activities, joining field trips, working on interdisciplinary team projects, writing reflection essays, participating in metacognition meetings, and revising project deliverables based on feedback. Figure 2 exhibits how the ISC and the IPBLC activities are designed for students to practice and develop the above-mentioned transferable skills.

Table 1: ENDEAVR Student Learning Outcomes and Course Activities/ Deliverables

Learning outcomes	Activities/ Deliverables
1. **Interdisciplinary seminar course (ISC)**	
1.1. Define interdisciplinary knowledge, research, education, and theory	▪ Join in seminars ▪ Answer questions in lecture reflection essays
1.2. Describe people's relationships with the built environment	▪ Join in seminars ▪ Answer questions in lecture reflection essays
1.3. Identify examples of how technologies have impacted the evolution of cities	▪ Join in seminars ▪ Answer questions in lecture reflection essays
1.4. Explain the background, methodological fundamentals, and societal relevance of various disciplines for smart and connected communities	▪ Join in seminars ▪ Answer questions in lecture reflection essays
1.5. Demonstrate how the use of interdisciplinary knowledge related to architecture and engineering can be used to solve open challenges in smart and connected communities	▪ Tour the targeted community ▪ Develop a problem statement that the team aim to solve for the community client and a plan for actions in the coming semester
1.6. Demonstrate metacognition, brainstorming, and teamwork skills for interdisciplinary collaboration	▪ Create individual intellectual autobiography ▪ Form interdisciplinary team ▪ Create a team name and team logo. ▪ Propose team building activities with a budget of less than $300. ▪ Submit a video that documents team building activities
2. Interdisciplinary project-based learning courses (IPBLC)	

2.1. Critically analyze a problem confronting their community client and break it down into causes	▪ Read assigned materials ▪ Tour the targeted community ▪ Submit progress report for *stage 1: background investigation* and *stage 2: goals & objectives*
2.2. Apply metacognition, brainstorming, and teamwork skills to collaborate with team members from other disciplines effectively	▪ Write and keep meeting minutes ▪ Develop and update task schedules ▪ Join metacognition breakfasts ▪ Complete project collaboration mind map ▪ Fill in reflections forms
2.3. Creatively construct solutions that involve knowledge, facts, techniques, or rules from multiple disciplines	▪ Submit progress report for *stage 3: analysis & alternatives* and a final report
2.4. Think reflectively to evaluate diverse ideas	▪ Submit progress report for *stage 4: evaluation*
2.5. Effectively interpret and express ideas through written, oral, and visual communications	▪ Present proposed solutions at midterm and final presentation ▪ Produce posters ▪ Create team project webpage StoryMaps

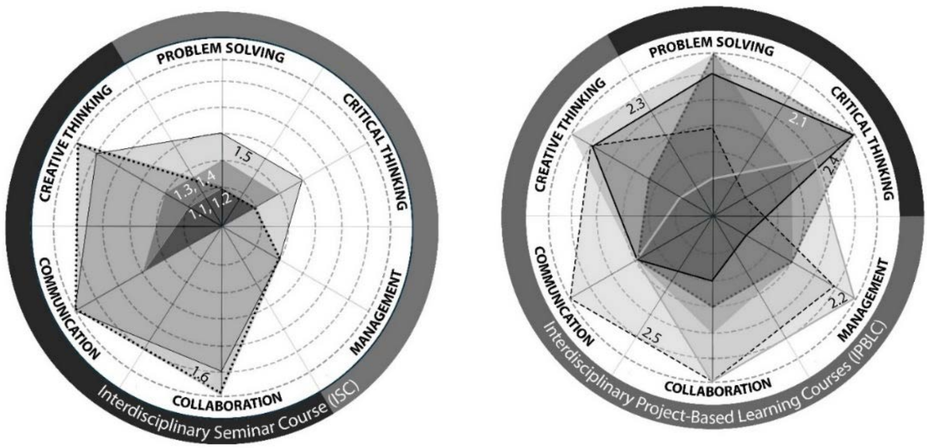
By teaching students how to work as members of an interdisciplinary team and by conducting team-building activities, the ISC aims to promote collaboration, communication, and creative thinking skills.

As Figure 2 shows, student learning outcomes 1.5 and 1.6 and the corresponding activities are designed to enhance all six skills, especially collaboration, communication, and creative thinking. On the other hand, various project-based activities, assignments, and deliverables in the IPBLC, such as 2.1, 2.3, and 2.4, target students' problem solving and critical thinking skills using different approaches. The ISC and the IPBLC complement each other, providing a comprehensive training for the ENDEAVR students.

In Fall 2019, an ISC was offered both face-to-face and online. The course included one interdisciplinary studies lecture, five smart and connected communities lectures, one community engagement lecture, one panel discussion, three team building sessions, two field trips, and one industry partner-offered training session.

In Spring 2020, four existing capstone courses, namely an urban planning capstone course, a landscape architecture capstone design studio class, a visualization studio class, and a computer science machine learning class, were converted into ENDEAVR IPBLCs. A total of 104 undergraduate and graduate students from civil, electrical, and mechanical engineering; computer science; landscape architecture; urban planning; and visualization were successfully trained by ENDEAVR IPBLCs.

Figure 2: ENDEAVR Training Main Skills and Learning Outcomes



Note. 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 2.1, 2.2, 2.3, 2.4, and 2.5 refer to the learning outcomes and activities outlined in Table 1.

Pilot Project Implementation

Recruitment

In Fall 2019, the ENDEAVR faculty and administration team conducted various activities to recruit students, including campus-wide bulk emails dissemination, flyers distribution, presentations and information sessions, and student organizations outreach (especially minority-focused student organizations). Meanwhile, the ENDEAVR Institute utilized social media, such as Facebook, LinkedIn, and YouTube as recruitment and communication channels.

As a way to invite faculty passionate about interdisciplinary teaching to join the ENDEAVR program, a project introduction was posted in the College of Engineering and the School of Architecture. In Spring 2020, four existing capstone courses enrolled in the ENDEAVR program and became ENDEAVR-affiliated courses.

To attract industry partners to the ENDEAVR program, in May 2019 the ENDEAVR faculty and administration team organized and hosted the ENDEAVR Tech Summit. More than 50 industry professionals, community leaders, and university educators attended the conference. The Tech Summit included presentations by the ENDEAVR team, participant roundtable discussions, and tech demos featuring autonomous vehicles.

To enhance the ENDEAVR program's community impact, an ENDEAVR open house event was organized. In March 2020, more than 100 faculty and students traveled to Nolanville to visit the community and participate in an open house event. At the event, the ENDEAVR program demonstrated the applications of a variety of innovative technologies, such as autonomous vehicles, robotics, drones, and artificial intelligence (AI)-based technologies (e.g., image processing systems). This event attracted a large number of local residents and the local media and served to advertise the program to the local community and solicit their support for and feedback on the ENDEAVR program and its implications for their community.

Team Building Activities

Team building instruction and practice are major components of the ENDEAVR program's training and took place in both the ISC and the IPBLC. As an initial assignment, each team collaboratively decided on a team name and designed a team logo and a mission statement. The ENDEAVR staff ordered every student a T-shirt with their team's logo as a way to create a stronger team bond and a cooperative team environment. Student team members were encouraged to work on projects, play games, complete exercises, and join other off-campus ENDEAVR events with their teammates. Several team building games were also organized in class to help groups get to know one another and begin functioning as a cohesive unit. As a way to encourage team building, the ENDEAVR program provided up to $300 per team to help fund their out-of-class activity's expenses. In Fall 2019, students proposed team building activities at the beginning of the semester, recorded their activity progress throughout the semester, and submitted a video sharing their team-building journey at the end of the semester. The student activities included camping, dining, visiting entertainment venues, online gaming, and field trips. These team building efforts aimed to enhance team member communication, build trust, and create positive group dynamics, which are important for the successful execution of the ENDEAVR team project.

Interdisciplinary Project Development

Interdisciplinary project development is the core component of the ENDEAVR program's training and was carried out throughout both the ISC and the IPBLC. In Fall 2019, five pioneer ENDEAVR student teams started their interdisciplinary projects as part of the ISC, in collaboration with the community and industry partners. Each project team was comprised of four to six students from three to five disciplines/majors. In spring 2020, a new cohort of 87 students took IPBLCs and joined the program. Thirty-eight of these students joined the existing five teams, and the other 49 students formed another five interdisciplinary teams. After the reformation, each project team was comprised of 10-12 students representing five to eight disciplines/majors.

1) Pre-project preparation: To clarify the program goals for the participating ENDEAVR students and help them understand the community context, faculty members, community leaders/residents, and industry professionals co-wrote a statement of challenges. In the 2019-20 pilot phase, the statement of challenges clearly described five primary problems faced by Nolanville residents. All ENDEAVR students were required to read through this document, choose one or two challenge statements, and propose initial conceptual solutions to address the selected challenge(s).

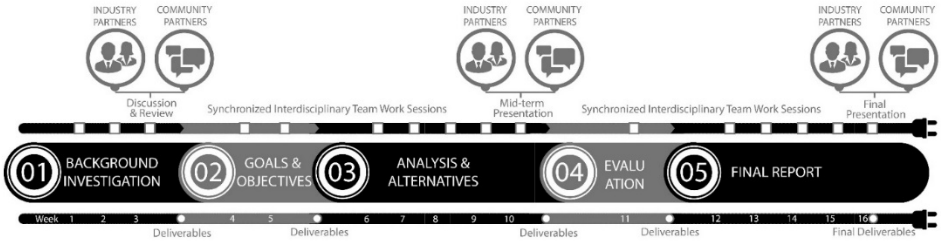
Besides the statement of challenges, the ENDEAVR faculty, TTC, and community leaders provided the students with the background documents and datasets relevant to Nolanville, including comprehensive master plans, public engagement meetings results, and social demographic and geographic data. Students were encouraged to read these materials as a way to inform their initial solution concepts.

2) Interdisciplinary team formation: An innovative "speed dating" activity was conducted to ensure that each IPBLC student team was composed of members who all shared a common project interest and had at least one member from each discipline. To begin, the IPBLC instructor called for two or three volunteers to serve as the student team leaders. These volunteers had one week to prepare a brief speech expressing their project interests and proposed initial solution concepts, which they then presented during class to the remaining ENDEAVR students. From there, the remaining ENDEAVR students had conversations with the team leaders whose team they potentially wanted to join. Students were required to share their resumes with two of the team leaders. Next, the team leaders reviewed the received resumes and completed a Google Form indicating their team member selection preferences. Lastly, the ENDEAVR faculty and staff finalized team membership based on the team preferences, as well as each team's disciplinary composition.

Once the student project teams were formed, they were asked to describe their project goals and objectives. A local community advisor was assigned to each team based on their expertise. A graduate assistant was also assigned to each team as a consultant. Student project teams were encouraged to conduct team building activities, as well as visit the community and communicate regularly with their local community advisor.

3) Project development: The ENDEAVR faculty and staff developed an ENDEAVR-Interdisciplinary Team Project (ENDEAVR-ITP) guide, which shows student teams how to complete their team project through a five-stage process: (1) background investigation, (2) goals and objectives, (3) analysis and alternatives, (4) evaluation, and (5) final report (Figure 3).

Figure 3: Five-Stage 'Plug-and-Play' ENDEAVR–ITP Process



The ENDEAVR-ITP guide also serves as a "plug-and-play" framework for converting an existing capstone course into an ENDEAVR-IPBLC. Figure 3 shows the IPBLC components necessary to be "plugged" into an existing capstone course. Besides the activities and deliverable requirements, weekly interdisciplinary teamwork sessions are essential IPBLC components and need to be coordinated around other required courses to ensure student attendance. In the program's pilot phase, the ENDEAVR faculty and students used these teamwork sessions to discuss project ideas, participate in metacognitive practice, and deliver presentations. In addition to the class sessions, faculty members offered metacognition-focused breakfast sessions and additional consultation sessions for each student team throughout the project development process. As was done in the ISC, the ENDEAVR program sponsored up to $500 per team to help fund project expenses such as equipment and materials, software licenses, and service registration.

Table 2 details the ENDEAVR program's five-stage ITP timeline for a 15-week IPBLC. At each of the five stages, the ENDEAVR program provided corresponding guidance and resources to facilitate student project activities. Since IPBLCs were three- to six-credit hour courses, students were expected to spend at least six hours per week on interdisciplinary project development. Typical weekly ENDEAVR IPBLC activities are described in Table 3.

Table 2: The ENDEAVR Program's Five-Stage ITP Timeline in a 15-week IPBLC

	Duration	Activities/ Deliverables	Guidance/ Resources
Stage 1: Background Investigation	Week 1-3	▪ Read assigned materials. ▪ Tour the community ▪ Choose one or two targeted key problems.	o Background inventory documents o Previous relevant students project work review

		▪ Consult with industry advisors and community clients. ▪ Write meeting minutes. ▪ Submit progress report for *Stage 1: Background Investigation*	o Recommended literature, datasets, and videos o Community field trip map o Contact information of the industry and community advisors o Meeting minute template o Report template with the detailed requirement for *Stage 1: Background Investigation*
Stage 2: Goals & Objectives	Week 4-5	▪ Develop overall goals and objectives for ITP. ▪ Join metacognition breakfasts. ▪ Explain how work from each discipline contributes to the goals and objectives. ▪ Write meeting minutes. ▪ Develop task schedules. ▪ Submit progress report for *Stage 2: Goals & Objectives*	o Mind map template for metacognition practices o Faculty consultation sessions o Gantt chart template o Report template with the detailed requirement for *Stage 2: Goals & Objectives*
Stage 3: Analysis & Alternativ es	Week 6-10	▪ Generate a range of creative alternatives (e.g., plans, designs, prototypes) ▪ Join metacognition breakfasts. ▪ Write meeting minutes. ▪ Update task schedules ▪ Present analysis and alternatives to industry advisors and community clients (Project Mid-term Presentation) ▪ Produce posters	o $500 for project development o Faculty consultation sessions o Mind map template for metacognition practices o Report template with the detailed requirement for *Stage 3: Analysis & Alternatives*

		▪ Submit progress report for *Stage 3: Analysis & Alternatives*	
Stage 4: Evaluation	Week 11	▪ Write meeting minutes. ▪ Gather feedback from industry advisors and community clients. ▪ Critically evaluate the proposed alternatives ▪ Update task schedules ▪ Submit progress report for *Stage 4: Evaluation*	o Industry and community advisors' consultation sessions o Report template with the detailed requirement for Stage 4: Evaluation
Stage 5: Final Report	Week 12-15	▪ Finalize solutions. ▪ Submit a final report. ▪ Create a Webpage with Story Maps ▪ Fill in a reflection form. ▪ Present ITP work to industry advisors and community clients (project final presentation)	o Faculty consultation sessions o Story Maps tutorial o Reflection form o Final report template with detailed requirement

Table 3: Typical Weekly ENDEAVR IPBLC Activities

Monday	Tuesday	Wednesday	Thursday	Friday
▪ Organize/attend an interdisciplinary team meeting. ▪ Write meeting minutes. ▪ Update task schedule	▪ Work on team projects (e.g., data collection, data analysis, solution proposals, report writing, etc.)	▪ Attending in-class interdisciplinary teamwork session. ▪ Write meeting minutes	▪ Join a project development consultation session. ▪ Revise work based on the feedback	▪ Work on team projects

PROGRAM EVALUATION

Methods

To understand the ENDEAVR program's student impact, as well as its strengths and weaknesses, the Education Research Center (ERC) was commissioned as an external evaluation team. In Spring 2020, the ERC adopted a mixed- method study to assess the pilot ENDEAVR program. The study involved quantitative pre- and post- surveys and a qualitative case study (Yin, 1994) using focus group discussions. Five survey participants were randomly selected to each receive a $50 e-gift card. All focus group participants received a $25 e-gift card.

The survey instrument, ENDEAVR Inventory of Problem Solving/Critical Thinking Skills, was adapted from the Heppner and Petersen (1982) Personal Problem-Solving Inventory. The survey contained three problem solving-focused sections: (a) problem solving confidence (10 items), (b) approach-avoidance style (16 items), and (c) personal control (five items). The survey instrument's last section focused on student's critical thinking and contained 11 items. All perceptual items used a four-point Likert-type scale with 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree.

Focus group discussions (Ryan et al., 2014) were designed to gather rich, in-depth qualitative information from the students. The discussions aimed to understand how students perceive their ENDEAVR experiences in terms of skill development, working with community advisors and in interdisciplinary teams. Focus group participants were also asked to suggest ways in which the ENDEAVR program could be improved for future cohorts. Two focus groups discussions were conducted, recorded, and transcribed via Zoom video conferencing platform. Each focus group discussion lasted approximately 90 minutes.

Results

Surveys

Of the 104 undergraduate students who participated in the pilot ENDEAVR IPBLC, 68.3% ($n = 71$) participated in the pre-survey; 61.5% ($n=64$) participated in the post-survey. Of those, 41 students responded to both the pre- and post-surveys.

Since the Personal Problem-Solving Inventory was validated at the subscale level (i.e., problem solving confidence, approach-avoidance style, and personal control), all problem-solving skills analysis was conducted using a mean score for the items within each of the three subscales. For the Inventory's critical thinking section, an exploratory factor analysis was conducted on the 11 included items, yielding two factors with Eigenvalues greater than 1. The two factors were related to study skills (6 items, $a = 0.81$) and self-reflection (3 items, $a = 0.78$).

Two of the 11 items did not factor onto a reliable scale and were removed from the analysis.

Table 4 and Table 5 show the ENDEAVR students' problem-solving and critical thinking mean scores for the pre- and post-surveys. The pre-survey results showed that students reported a relatively high level of agreement with statements on the approach-avoidance scale (M = 2.93, SD = 0.29), meaning that students tended to choose not to engage in avoidance behaviors, such as rushing to a solution. Meanwhile, students had relatively low confidence in their study skills (M = 1.84, SD = 0.45) and self-reflection (M = 1.91, SD = 0.53). From the post-survey, in contrast to pre-survey results, students' mean scores on the study skills (M = 3.27, SD = 0.41) and self-reflection (M = 3.05, SD = 0.51) scales were the highest across the five scales ((three problem-solving scales (i.e., problem-solving confidence, approach-avoidance style, and personal control) and the two critical thinking scales (i.e., self-reflection and study skills)), with the personal control scoring the lowest.

Table 4: ENDEAVR Students' Problem-Solving Behaviors and Critical Thinking: Pre-Survey

	Pre-survey participants (n = 71)	
Scale	*M*	*SD*
Problem-solving behaviors		
Problem-solving confidence (n = 69)	2.83	0.29
Approach-avoidance style (n = 70)	2.93	0.29
Personal control (n = 70)	2.76	0.40
Critical thinking skills		
Study skills (n = 70)	1.84	0.45
Self-reflection (n = 71)	1.91	0.53

Source. ENDEAVR Inventory of Problem-Solving/Critical Thinking Skills.
Note. Mean values for items are based on a 4-point scale: 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree.

Table 5: ENDEAVR Students' Problem-Solving Behaviors and Critical Thinking: Post-Survey

Scale	Post-survey participants (n = 64)	
	M	*SD*
Problem-solving behaviors		
Problem-solving confidence (n = 59)	2.85	0.30
Approach-avoidance style (n = 62)	3.00	0.25
Personal control (n = 61)	2.68	0.50
Critical thinking skills		
Study skills (n = 64)	3.27	0.41
Self-reflection (n = 63)	3.05	0.51

Source. ENDEAVR Inventory of Problem-Solving/Critical Thinking Skills.
Note. Mean values for items are based on a 4-point scale: 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree.

Table 6: ENDEAVR Students' Problem-Solving Behaviors and Critical Thinking: Pre- to Post-Survey

Scale	Pre-survey (n = 41)		Post-survey (n = 41)			
	M	*SD*	*M*	*SD*	*t*	*p*
Problem-solving behaviors						
Problem-solving confidence	2.81	0.32	2.85	0.31	1.00	0.324
Approach-avoidance style	2.89	0.29	2.96	0.25	1.73	0.092
Personal control	2.72	0.39	2.74	0.53	0.22	0.827
Critical thinking skills						
Study skills	1.95	0.46	3.06	0.53	7.90	0.001**
Self-reflection	1.88	0.45	3.26	0.39	12.8	0.001**

Source. ENDEAVR Inventory of Problem-Solving/Critical Thinking Skills.
Note. Mean values are based on a 4-point scale, with 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree.
** $p < .01$.

Dependent samples t-tests (Table 6) were conducted using the survey results from the 41 students who completed both the pre- and post-surveys to measure intra-personal changes in the mean score for the above mentioned five scales before and after the ENDEAVR IPBLC training. Compared to the pre-survey, the post-survey results did not show statistically significant changes in their problem-solving behaviors (all three scales showing insignificant pre-post differences). In contrast, both critical thinking scales showed statistically significant increases from pre- to post-survey (study skills, $p < 0.001$; self-reflection, $p < 0.001$). Statistically significant increases in both critical thinking scales, the study skills and self-reflection scales, indicated that students' perceived improved critical thinking skills after participating in the ENDEAVR program.

Focus Groups

The first focus group was comprised of six females and one male; the second focus group was comprised of four females and three males. Overall, focus group participants included students from landscape architecture, computer science, visualization, and urban planning.

Focus group participants identified three ENDEAVR program components they would emphasize if trying to encourage a friend to participate in the next ENDEAVR cohort. First, participants mentioned that when talking with a friend who was considering ENDEAVR, they would stress the intellectual freedom and responsibility that was integral to the ENDEAVR experience. Participants also mentioned that when talking with a friend, they would emphasize ENDEAVR's focus on realistic, authentic experiences—particularly the opportunity to interact with an actual client—as an attractive program feature. One student noted: *"[ENDEAVR] filled some gaps in our curriculum as far as making things more realistic."* Finally, some participants identified ENDEAVR's impact on their professional skills and marketability as important reasons for encouraging a friend to participate in the next cohort. One participant mentioned: *"I saw [ENDEAVR] as a great resume project. This is a concrete thing that I can put on my resume and show people that I accomplished things using computer science, using machine learning."*

All focus group participants reported that their individual team had been assigned one principal community advisor. However, the teams' overall experiences with their community advisors were mixed. Some participants reported a somewhat non-existent relationship with community advisors. They recommended the ENDEAVR program recruit community advisors who could make a firm time commitment to regular team meetings. Conversely, other respondents described a very positive relationship between community advisors and team members, *"I loved ours! She was really engaged in the process."*

Some participants identified collaboration with colleagues from different academic disciplines as an area in which their skills increased resulting from their

ENDEAVR program participation. Although many of the student participants were accustomed to group projects prior to ENDEAVR, most had never collaborated on an interdisciplinary group project. One student stated: *"It was definitely interesting to see all the collaboration between the disciplines. . .. I definitely saw a lot of different perspectives. . .and seeing the difference between all the different disciplines."*

Participants from both focus groups discussed the challenges they had encountered in learning to work as a cohesive team to complete their ENDEAVR projects. Common barriers noted by the students related to the fact that teams were composed of students from different academic majors and most participants were not familiar with interdisciplinary collaboration. One student reported, *"What happened with us is that we kind of struggled with finding something that we could all do together."* Communication challenges arose as teams worked to integrate diverse disciplinary perspectives and diverse disciplinary–specific vocabularies into one cohesive group project. For example, a student said, *"[Another student] had to teach some of us the vocabulary for machine learning, because for us, it's more, like, what does data mean in this major? Data means words for landscape architecture and numbers for computer science.*" Several focus group participants also identified scheduling meetings as a barrier to creating a seamless team experience. As a student reported, *"Some of my computer science members had classes during all of our proposed meeting times outside of the studio and outside of classes."*

In terms of the preproject training and preparation, participants had mixed experiences. Some focus group participants took the fall semester ISC. They remarked, *"We learned to know each other very well. I think the first thing was, we played a game to build a close connection—friendly connections in the team." "It [the ISC] gave me a foundation to help understand what others were doing and what I could do to integrate with others."* Other participants who did not complete the ISC stated that the ENDEAVR project had not been thoroughly explained to them prior to beginning the semester. A participant in computer science, for instance, said, "We did not know what ENDEAVR was. We did not know it was going to be part of our class." These participants expressed frustration with the lack of team bonding opportunities. One student, for example, explained, *"[It would be helpful] if we just had that 'pre-interaction', and understanding of each other's skills and what each major had to offer."*

LESSON LEARNED

The Coronavirus Pandemic

In Spring 2020, the COVID-19 pandemic posed significant challenges to the ENDEAVR program, especially with its student project activities requiring a significant amount of team-based and community engagement activities. In response to the pandemic, the university canceled all Spring 2020 face-to-face classes and converted them to an online format beginning the week of March 23rd. The ENDEAVR faculty team moved all affiliated courses and project activities online using Zoom (Zoom Video Communications, 2022). The ENDEAVR leadership team continued to guide and support the 10 student teams' project development remotely.

Despite these efforts, the shift to online instruction and the coronavirus pandemic prevented students from visiting Nolanville in person, installing needed sensors and equipment, and collecting onsite data. Originally, the ENDEAVR program intended to utilize a "citizen science" approach to collect data and assist student teams. Citizen science is the practice of involving citizens in scientific inquiry processes to generate new knowledge (Silvertown, 2009). The ENDEAVR program expected to collaborate with Nolanville High School students on some of the project activities. However, this plan was canceled as the local high school students were not allowed to visit the project sites. These situations compromised the ENDEAVR program's real-world, hands-on learning experiences. Instead, the program pivoted to have students design projects based solely on secondary data, resulting in some student teams' solutions being limited to the conceptual phase.

Lack of Team Bonding

Although the ENDEAVR program students conducted team building activities in both the ISC and the IPBLC, students who took the fall semester ISC tended to become acquainted on a personal level and credited ISC with the strong team bonding. Students who received full ENDEAVR training credited their ISC experience with helping them understand the different disciplines involved in the ENDEAVR program and what the students from different disciplinary areas bring to a team.

Team bonding issues emerged for students who did not enroll in the fall semester ISC before taking the spring semester IPBLC. From Fall 2019 to Spring 2020, students who were enrolled in the ENDEAVR-affiliated courses automatically joined the program, formed teams, and started project development. Most students had not received the ISC training in the fall. The tight IPBLC spring semester schedule left limited time for introducing each discipline, explaining how to function in an interdisciplinary setting, and conducting team building activities. Also, the instructional shift that resulted from the COVID-19 pandemic constrained students' ability to interact with each other.

Consistent with findings from a previous study (Frank et al., 2003), the lack of team bonding led to problems in developing high-functioning teams. As some students were not accustomed to interdisciplinary collaboration, integrating various disciplinary ideas into one cohesive, interdisciplinary group project was challenging. One case study participant expressed,

> *It was hard to kind of, like, get everyone's ideas to fit nicely into one, big integrated solution…They were just, like, sticking to their discipline, and everyone kind of had their own deliverables for their studio, so it kind of broke off that way.*

Organizational Issues

Some college-level and/ or departmental-level policies prevented students from enrolling in both the ENDEAVR program's ISC and IPBLC. The ISC enrollment was not possible for some students due to existing internship or study abroad requirements for the fall semester. In some disciplines, students could not take one of the ENDEAVR's IPBLCs because their required course load had already reached the spring semester's maximum number of hours allowed. Some students found it hard to take both the ENDEAVR ISC and IPBLC because ENDEAVR ISC is elective and could not replace existing required courses in their degree plans. Incomplete ENDEAVR experience without the ISC prerequisite compromised the overall learning outcomes.

Working across different colleges and departments created challenges in securing a common class time that all team members could meet concurrently. Meanwhile, it was also difficult to find a common time for out-of-class team meetings. This resulted in teams having to hold meetings knowing some team members would be absent, limiting opportunities for team building and interdisciplinary learning and posing challenges to communication and project execution.

During ENDEAVR's pilot project phase, all students enrolled in the ENDEAVR-affiliated courses were automatically involved in the ENDEAVR program. However, such a mandatory enrollment led to having some students with little interest in interdisciplinary project/learning and not making equitable contribution to the projects. Although all ENDEAVR-affiliated courses allocated 50%-60% of the total course grade to the interdisciplinary project performance, some students still did not show the expected level of commitment which impacted the overall teamwork and learning outcomes.

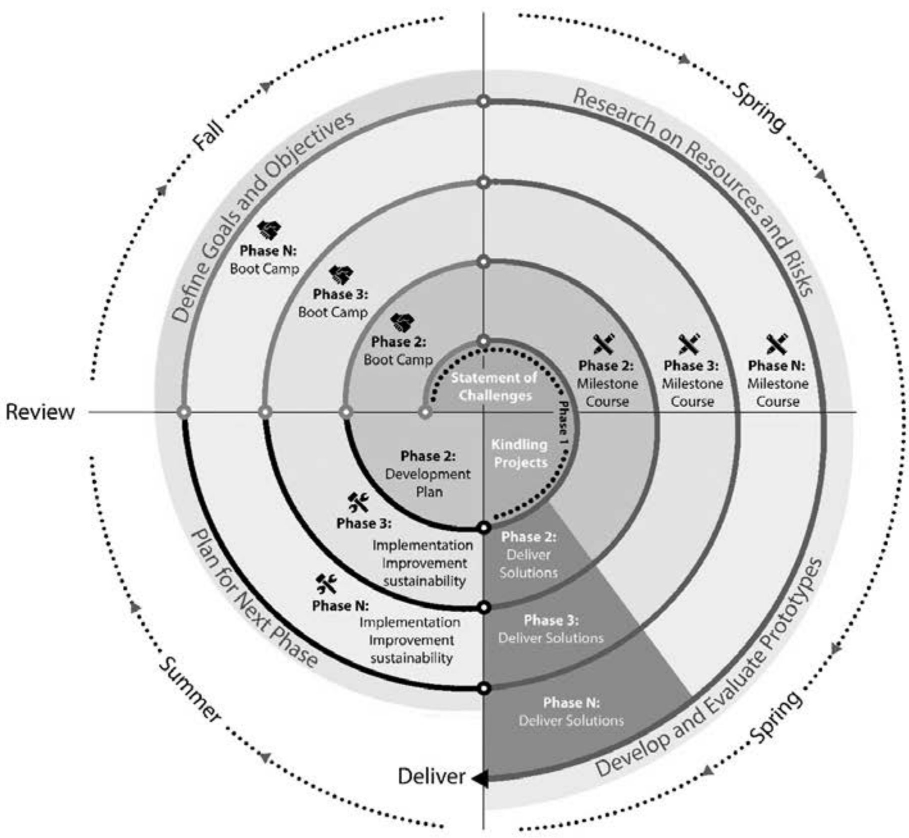
Aligned with existing studies (Fixson, 2009; Kurland et al., 2010), our ENDEAVR pilot experience brought to light that the university's current infrastructure is not completely compatible with this type of innovative and interdisciplinary pedagogical approach. Administrative and financial resources are constrained, separated by departments and colleges, and cannot sufficiently or effectively support interdisciplinary and project-based teaching/learning.

Long Term Community-University Relationship

Long-term, continuous commitment is needed to build trust between communities and higher education institutions. Previous studies have documented the difficulties in maintaining a long-term community-higher education relationship (Netshandama, 2010; Winkler, 2013). Higher education academic calendars do not always match up with community time frames, schedules, or requirements. Unmet expectations often hamper the long-term collaborative relationship.

In response to this challenge, the ENDEAVR PIs offer summer internship programs for students who want to continue working on the proposed smart city projects. Also, student teams are encouraged to register as a student organization or company. Students in these ENDEAVR program organizations continue to refine their proposals and implement projects for community clients as social entrepreneurs (Peredo & McLean, 2006). For some students, their ENDEAVR project could be a four-year-long community service experience (Figure 4).

Figure 4: ***The ENDEAVR "Spiral" for Project Development and Implementation***



The 2019-2020 pilot ENDEAVR student cohort developed interdisciplinary projects to address Nolanville's challenges in public health, transportation, safety, economic development, and environmental quality. Their project summaries are published on the ENDEAVR YouTube channel (https://youtube.com/playlist?list=PL3YGtIIN3xZTIEzWDwP3WcMzD23-yWzvi). Guided by the ENDEAVR "Spiral" as illustrated in Figure 4, the leadership team encouraged the 2020-21 ENDEAVR studentscohort to continue addressing these same Nolanville challenges. In addition to the work in Nolanville, students explored smart-city solutions for four additional central Texas small towns: Caldwell, Copperas Cove, Huntsville, and Madisonville. Table 7 summarizes the ongoing ENDEAVR interdisciplinary projects.

Table 7: ***The Ongoing ENDEAVR Interdisciplinary Projects***

Location	Theme	Challenge	Key activities
Nolanville, TX	Smart mobility	▪ People with disabilities and older adults struggle to obtain needed transportation and health care	o Operate the ENDEAVRide with an on-demand transport service and a mobile telemedicine clinic
Nolanville, TX	Smart mobility	▪ Crossing trains often block traffic	o Develop a warning system with sensors and artificial intelligence that alerts residents ahead of time.
Nolanville, TX	Smart environment	▪ Litter accumulated in Nolan Creek	o Design and build an automatic trash remover
Nolanville, TX	Smart living	▪ Limited access to affordable and good-quality fresh food	o Operate a grocery truck with an artificial intelligence system to manage inventory
Copperas Cove, TX	Smart mobility	▪ Traffic congestion	o Identify spatial temporal traffic congestion hotspots by using street cameras and artificial

			intelligence to count traffic
Huntsville, TX	Smart governance	▪ Lack of efficient digital platform for communication between residents and the city	o Develop a 3-1-1 smartphone app for routine inquiries and non-urgent community concerns.
Caldwell, TX	Smart environment	▪ Inadequate public awareness of water conservation	o Build a rainwater collection system with an interactive tablet display
Madisonville, TX	Smart living	▪ Outdated water infrastructure	o Improve water infrastructure through pipe leakage prediction

CONCLUSION

This paper introduces an innovative interdisciplinary, project-based, service-learning pedagogical approach—the ENDEAVR program. This approach aims to address the growing need for interdisciplinary training in higher education specifically related to smart and connected communities.

In the 2019-20 academic year, a diverse team piloted the program, training more than 100 students from urban planning, computer science, civil engineering, electrical engineering, landscape architecture, and visualization. The program evaluation team found that the ENDEAVR program enhanced students' critical thinking skills, although the program's overall impact was constrained by the COVID-19 pandemic, lack of student team bonding, and university organizational issues.

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