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Development of A Holistic Cross-Disciplinary Project Course Experience as a Research Platform for the Professional Formation of Engineers

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Abstract

Although engineering graduates are well prepared in the technical aspects of engineering, it is widely acknowledged that there is a need for a greater understanding of the socio-economic contexts in which they will practice their profession. The National Academy of Engineering (NAE) reinforces the critical role that engineers should play in addressing both problems and opportunities that are technical, social, economic, and political in nature in solving the grand challenges. This paper provides an overview of a nascent effort to address this educational need. Through a National Science Foundation (NSF) funded program, a team of researchers at West Virginia University has launched a Holistic Engineering Project Experience (HEPE). This undergraduate course provides the opportunity for engineering students to work with social science students from the fields of economics and strategic communication on complex and open-ended transportation engineering problems. This course involves cross-disciplinary teams working under diverse constraints of real-world social considerations, such as economic impacts, public policy concerns, and public perception and outreach factors, considering the future autonomous transportation systems. The goal of the HEPE platform is for engineering students to have an opportunity to build non-technical—but highly in-demand—professional skills that promote collaboration with others involved in the socio-economic context of engineering matters. Conversely, the HEPE approach provides an opportunity for non-engineering students to become exposed to key concepts and practices in engineering. This paper outlines the initial implementation of the HEPE program, by placing the effort in context of broader trends in education, by outlining the overall purposes of the program, discussing the course design and structure, reviewing the learning experience and outcomes assessment process, and providing preliminary results of a baseline survey that gauges students interests and attitudes towards collaborative and interdisciplinary learning.

1. Introduction

While engineering graduates are well versed in the technical aspects of the profession, it is likely that many graduates do not possess sufficient skills to understand the socio-economic context of their work and to engage other stakeholders in addressing engineering challenges in the 21st century effectively. To remain a world economic leader, the U.S. must realize growth in the engineering workforce, and perhaps more importantly, produce engineers who are more competent in their problem-solving approaches. However, addressing only the matter of quantity will not attend to the increasing complexity of 21st-century engineering challenges. Engineers have been deficient in skill sets and disciplines outside engineering areas [1]. This new breed of engineers needs to be not only a problem *solver* but also a problem *definer,* leading multidisciplinary teams of professionals in setting agendas and fostering innovation [1], [2]. To address these challenges, there has been a call to increase the number of engineers [3]. An emphasis has also been placed on broadening undergraduate engineering experiences to encourage the study of socio-economic context and to engage in collaborative and interdisciplinary education with students and faculty from other disciplines. Conversely, within the social sciences and humanities, there has been a growing interest in encouraging a better understanding of the technical aspects of science and engineering matters. This joint interest has led to a significant, but still small number of courses being developed and offered across the country. The American Society for Engineering Education, through the work of Tobias, maintains an archive of some of these courses [4]. In short, although the university structure is conducive for cross-disciplinary experiences in the curriculum, such experiences are not common.

In 2019, a team of faculty at West Virginia University received a grant from the National Science Foundation to initiate a cross-disciplinary learning initiative to expose engineering students to key concepts and skills in the social sciences and to provide an orientation to engineering principles and practices to social science students. After months of course design, an initial course was offered in the spring 2020 semester. The course, now underway, focuses on the case of autonomous vehicle adoption in the transportation systems of the state of West Virginia. The purpose is for students to have a true multi-disciplinary experience that applies a holistic engineering approach to contemporary open-ended and complex engineering problems. In this way, engineering students can expand the problem-solving toolbox beyond the realm of traditional engineering through a collaborative exchange with other disciplines. In turn, students in other disciplines can gain experience working side-by-side with engineers, expanding their understanding of and collaboration skills related to engineering perspectives on problems with broad social implications. The open-ended and complex problem explored in this project is one that the National Academy of Engineers (NAE) identified as a grand challenge [5], i.e., "*Restore and Improve Urban Infrastructure*," with a specific focus on future transportation systems and infrastructures dominated by connected and autonomous vehicles.

2. Significance of the holistic engineering approach

Holistic Engineering is an *approach* to the engineering profession, rather than a technical discipline such as civil, electrical, or mechanical. It is inspired by the realization that traditional engineering does not adequately harness "nontechnical" skills in its problem-solving repertoire. It asks engineers to look outward, beyond the fields of math and science, in search of solutions to entire problems. The next-generation engineers must attempt to understand the human condition in all of its complexity, which requires the study of literature, management, psychology, and communication, among other fields [1]. Complexity is especially evident when human decisions play a role in the system; for example, the dynamic functioning of a transportation network largely depends on different user groups with diverse characteristics.

While engineers are highly proficient at solving problems, they are not the only professionals who are, and perhaps they could be even better problem solvers if they were more aware of the types of tools used by others. For example, it is well known that excessive congestion is among the most complex and costly problems associated with our transportation system. In traditional transportation engineering courses, students are taught that congestion is an engineering quantity that is exclusively expressed as vehicle or passenger volume per time, such as *vehicles/hour* or *passengers/minute*. Subsequently, engineers for decades have sought solutions to congestion in the form of faster vehicles, optimized controls, construction of new facilities, and reductions in travel demand. However, a civil engineer working alongside an economist might prompt to solve congestion by adjusting the price to use transportation infrastructures to allocate the limited spaces available better. Currently, civil engineers implement different transportation demand management strategies (e.g., road congestion pricing, high occupancy toll lanes) to reduce congestion. The incorporation of economics would enhance the engineer's "toolbox" and broaden the solution space. Collaboration with economists will help them, for example, to determine and impose the social costs of driving on road users (i.e., cost of adding an additional car to traffic flow), as social costs usually are not paid by taxes or fees [6]. A driver supposedly will impose a higher burden on others, and thereby incur a higher social cost if he or she wishes to travel during peak periods rather than off-peak periods. Therefore, Holistic Engineering is based on a new tenant of what engineering is, and perhaps more importantly, who engineers are—namely, technically adept people who serve humanity through the application not solely of math and science, but of an array of disciplines.

3. Literature review

Section 3.1 provides an overview of the engineering education landscape and professional formation challenges, and section 3.2 summarizes cross-disciplinary experience evaluation theories, models, and assessment frameworks.

3.1 Engineering education and professional formation challenges

If engineers are to play a substantial role in addressing global grand challenges—and they should—they necessarily will collaborate with constituencies across a broad spectrum of expertise, viewpoints, and skill sets, including stakeholders who may have conflicting interests [7], [8]. In 2006, in-depth interviews with industry practitioners, recent engineering graduates, and leaders of engineering firms were conducted to identify the skill gap of engineering graduates, industry requirements, and current curriculum [9], [10]. The study concluded that the engineering profession must advance in its awareness and application of skills in communications, management, and public policy.

Unfortunately, the occurrence of true multidisciplinary learning experiences to facilitate the professional formation of engineers remains rare. For example, engineering capstone courses claim to be multi-disciplinary but in Civil Engineering (CE), such courses almost universally consist of a design problem that incorporates two or more CE domains, falling far short of a true multi-disciplinary or cross-disciplinary experience as advocated in the references cited herein [11]. However, there are at least a few documented examples of courses offered simultaneously to engineering and non-engineering students [12], [13] and courses offered in team settings on open-ended problems [14], [15]. While the references are convincing in their claims of the significant benefits of these course structures, the extent of the formal research-based learning from these course offerings is limited. In the following subsection, team learning theories,models and frameworks used in evaluating student learning in a cross-disciplinary environment are summarized.

3.2 Team learning theories, models, and frameworks in cross-disciplinary environments

Team environments, such as the cross-disciplinary course described herein, provide a platform that encourages the formulation of creative and innovative design and solutions for engineering problems. This is derived, in part, from the diversity of team participants' educational backgrounds and expertise. Several engineering programs have implemented cross-disciplinary learning experience by integrating multiple major engineering disciplines such as electrical, computer, and mechanical engineering. Engineering undergraduates of Purdue University worked with engineering students from different disciplines on problems related to non-profit organizations (e.g., community service agencies, schools, museums, and local government offices). Students developed increased bonding with team members and with the community and enhanced communication skills in the process [16]. This program sometimes included non-technical students in the team. Fruchter and Emery [17] defined the learning of students in cross-disciplinary teams in four phases: island of knowledge, awareness, appreciation, and understanding. Ilgen et al. [18] proposed three similar stages in team learning: forming, functioning, and finishing. Diverse and complex perspectives of team members at the beginning converged to commonly agreed perspectives in a team learning environment. In addition, learning from the most knowledgeable and well-performing member(s) in the team increased with the difficulty level of assigned tasks. The literature on the evaluation of cross-disciplinary experiences reports the importance of measuring learning in terms of affective, behavioral, and cognitive variables or states [19]. Interviewing individual students, evaluating their written reflections in personal journals, and using pre- and post-surveys students' cross-disciplinary experiences can be assessed. Relatedly, conceptual and mathematical models provide a strong foundation to understand team learning [18]. Lei [19] developed a validated theoretical Cross-Disciplinary Team Learning (CDTL) model considering three dimensions (i.e., identification, formation, and adaptation). Assessed items were found interdependent on the dimensions and associated constructs. In this research, a cross-disciplinary team of students representing engineering, economics, and strategic communications collectively work on a contemporary problem-based project, and the Cross-Disciplinary Team Learning model (CDTL) presented in [19] was adopted to evaluate the professional formation of engineers. This model provides a framework that was being utilized to assess the HEPE course section in comparison to two traditional civil engineering courses. Three dimensions of this CDTL model and its associated constructs and assessment framework are presented in Section 4.3.

4. Methods

To better understand the purpose, scope, and approaches that are used in facilitating and assessing learning experiences and outcomes, it is first necessary to explain in greater detail the course design, purpose, and course implementation structure, which we do in Section 4.1 and 4.2.

4.1 Educational objectives and course design

Owing to the gaps in the engineering curriculum and professional formation of engineers, the HEPE course provides an open-ended and cross-disciplinary holistic project-based course for engineering students to explore its influence on their professional formation. The course design calls for multidisciplinary student groups to be established who will work together with five core faculty drawn from engineering, economics, and strategic communications. One group has been tasked with exploring technology and infrastructure issues and the other is responsible for exploring potential transportation impacts of emerging connected and automated transportation systems. Both teams are expected to apply engineering, economic, and strategic communications theories, knowledge, methods, and tools to contribute to the solution of this open-ended engineering problem.

The tools of economics offers additional perspectives and skills for students. First and foremost, the analytical and rigorous "economic way of thinking" will help engineering students to analyze the implementation of potential engineering solutions in a real-world setting. The economics way of thinking can offer a view of this problem couched in the context of market behavior and individual incentives. Economics can also bring numerous other specific problem-solving tools. One example is benefit-cost analysis, where engineering students can learn how to rigorously evaluate and compare costs and benefits of particular policy solutions that may involve considerations of many years. In addition to the unique economic approach to problems of resource allocation, economics offers many advantages to engineering students in terms of data management and analysis. Economics students can work with forecasting future patterns in engineering or economic data as well as with developing econometric models to test observed relationships.

Regardless of technological capabilities, if new infrastructure, systems, or products are not well understood and valued, they are not likely to be adopted and diffused through society [20]. Strategic communications students are trained to be goal-oriented and to conduct research to understand various stakeholder perspectives and values. They also know that opinion leaders must be engaged in campaigns to gain traction and that their messages must not only serve to inform and educate but often must assuage or persuade. Their use of social science research methods to ascertain public knowledge, attitudes, and likely behaviors, coupled with their strategic campaign approach to segment and prioritize key publics, will offer valuable insights for engineering students about the importance of identifying key stakeholders and facilitating positive engagement and education around public projects—particularly projects involving new ideas, processes and/or high costs.

In designing the course, the core faculty worked closely together to identify the case study for the multidisciplinary project. They agreed that that the socioeconomic dimensions of autonomous vehicle use and adoption, their potential impact on infrastructure costs and regulation, and the public and political saliency of the topic made this an excellent subject for the course. In addition, the faculty devoted time to learn more about each other's disciplinary orientations and approaches. For example, social science research may not be familiar to engineering faculty, whose work commonly revolves around physical systems in the lab and the field. However, qualitative and quantitative social science research methods can help faculty better evaluate their courses/curriculum and also help them incorporate these methods into student activities/assignments. Therefore, as part of this study, the participating faculty regularly engage with two social science research experts in engineering education who serve as mentors for survey, focus group, evaluation, and reflection best practices in course design and assessment.

In sum, the unique features of the HEPE offer the following features: (i) students working in teams, (ii) students working across disciplines, (iii) students working on an open-ended problem, (iv) students having access to professors from multiple disciplines, and (v) students having access to external expertise and critique. The next section (section 4.2) describes the details of the course offering.

4.2 Course implementation structure

Twenty-one students are enrolled in the initial Spring 2020 course offering (offered with title "*Technology Innovation: Engineering, Economics, Public Relations*"), where 12 students are majoring in engineering, seven students majoring in strategic communications and two students majoring in economics. The specific case study involves the *Impacts of the Implementation of Connected and Automated Vehicles*. By centering around a contemporary, complex, and open-ended problem, the learning experience relies on both technical and non-technical perspectives for feasible solutions. Therefore, students from all three areas of study offer necessary contributions and have access to the skill sets, methods, and perspectives of their counterparts in the other fields. They engage in a high-level synthesis whereby they add to the topic's body of knowledge through interim reports, a final report, and formal presentations. These deliverables are presented to the course instructors (i.e., project investigators) and an outside advisory panel consisting of experts in various aspects of the problem. The course is taught by two professors from civil engineering, one professor from strategic communication, and one professor from economics.

Apart from the four professors, the expert advisory panel, composed of professionals representing both the public and private sectors, is also involved with the course. Their roles are to: (1) independently evaluate the work of the students, and (2) provide expertise and resources for the students. A fifth professor is tasked with coordinating the course. This individual directly communicates with the professors who supervise the student groups. The course coordinator also ensures that the advisory panel is actively engaged with the course and facilitates interaction between the panel members, professors, and student groups as needed.

The course was designed to run as a "Task Force" model, wherein the governor's office serves as the (hypothetical) client. Specifically, a task force of engineering, economics, and media experts (here, students) was convened at the request of the governor to provide policy recommendations related to the future autonomous transportation system.

The research project hypothesizes that engineering students (i.e., the study group) participating in the cross-disciplinary open-ended problem-based HEPE format report higher levels of learning related to non-technical professional skills and professional tools than the students in the comparison groups. For comparison, we selected two civil engineering courses that are not cross-disciplinary as our comparison groups. We applied the CDTL framework (expanded below) in conducting this research. We investigated the difference between the study group and the comparison groups in terms of three CDTL learning dimensions in the pre-semester survey. The objective of this study is to present the analysis of the baseline data (i.e., pre-semester survey) to ensure no differences exist between the study group and the comparison groups prior to course participation and to evaluate the data collection instruments. As the semester progresses, the research team will assess the impacts of the cross-disciplinary HEPE on the study group's learning compared to the comparison classes in mid-semester and post-semester surveys.

4.3 Assessment framework for Cross-Disciplinary Team Learning (CDTL)

As discussed in Section 3.2, three dimensions of CDTL are to be assessed using established assessment constructs identified in the literature. Table 1 summarizes the key constructs of each dimension of CDTL. Several items evaluate students' responses by providing both quantitative (i.e., a Likert scale) and qualitative (i.e., open-ended) response options. The surveys are to be conducted in three stages (i.e., pre-, mid-, and post-semester) to track the evolution of engineering students' professional formation through cross-disciplinary course experiences.

Table 1. Three major dimensions of the CDTL framework and associated assessment constructs

Dimension #1: Identification	Self-assessment [17]; Information seeking [21] , [22]; Personal goal setting [21], [22]; Strategic planning [21] , [22]; Self-monitoring [21] , [22], [23].
Dimension #2: Formation	Team goal setting [18]; Leadership [24]; Role identification [18]; Trust [18]; Interdependence [25]; Peer feedback [25]; Expert feedback [25]; Communication and collaboration tools [26]; Awareness [17]; Appreciation [17].
Dimension #3: Adaptation	Goal alignment [24], [25]; Shared mental models [18]; Understanding [17].

4.3.1 Dimension #1: Identification

CDTL's identification dimension assesses students' readiness for team formation, which is critical to the successful completion of the project and the maximization of team learning [23]. Self-assessment of self-regulation strategies is the building block of this dimension.

4.3.2. Dimension #2: Formation

In this CDTL dimension, team members start to participate in a cooperative and collaborative process of team formation and functioning [18]. The team members move from individual project goals to defining team goals, and as such, utilize the expertise of individual team members toward project work. Many constructs are used by researchers to measure this dimension; selected constructs that are used in this research are listed in Table 1.

4.3.3 Dimension #3: Adaptation

This dimension assesses team learning at the latter stage of the team project after team members have been executing their respective project roles by aligning their individual project goals to shared team goals. Table 1 summarizes the key constructs to be used in assessing team learning of all three dimensions discussed above.

4.4 Learning experience data collection strategies

Pre-, mid- and post-course student surveys were developed for the spring 2020 offering of "*Technology Innovation: Engineering, Economics, Public Relations.*" For comparative purposes, the same pre-, mid- and post-survey are being administered to students enrolled in two traditional Civil Engineering courses. The advisory panel evaluates students' work and performance via an evaluation template twice: once at about the middle of the semester (completed) and the second at the end (pending). Student focus groups also will be conducted at the end of the semester to solicit additional information pertaining to the HEPE students' experiences.

Collected data are used to assess the course and its strengths and weaknesses in terms of students' learning, their motivation to learn, and their resultant confidence and competence across professional dimensions. The social science mentors worked with the three engineering faculty members to modify or develop surveys to assess students' confidence and perceived competence in various professional engineering dimensions, such as problem-solving, communication, working on multidisciplinary teams, and ability to understand the impact of engineering solutions from various economic and societal perspectives across multiple contexts.

In addition to the quantitative survey-based analysis, the mentors also worked with the engineering faculty to develop moderator guides for post-semester student focus groups. The focus groups will offer qualitative feedback from students to allow greater insights into their perspectives about course challenges, benefits, and suggestions. One/two optional class sessions will be used to obtain feedback from engineering students and non-engineering students, respectively. The moderator guide will guide participants through various types of questioning.

The professional advisory panel also provides qualitative and quantitative feedback (via a grading rubric) on the students' proposals, final projects, and presentations, and the faculty meet collectively during the semester to discuss qualitative observations and work through any course concerns/challenges. The survey and focus group analyses, the advisory board evaluations, the traditional Student Evaluation of Instruction results, and the professor reflections also will be shared with the project evaluator, who is the university's undergraduate director of academic excellence and assessment.

5. Pre-survey analysis and results

For the initial offering of the Multidisciplinary HEPE in the Spring 2020 semester, the research team administered the IRB-approved pre-semester student survey. This section analyzes and interprets the pre-semester survey responses gauging study group engineering students' knowledge base (total 12 responses) compared with two comparison groups of engineering students (total 18 and 11 responses from comparison groups 1 and 2, respectively). The intent of the survey was to establish a baseline for subsequent assessment over the course of the semester and for comparison to future course offerings. Student attitudes and opinions were solicited on the three dimensions of identification, formation, and adaptation. Most specifically, students' interest was assessed in exploring multi-disciplinary perspectives on engineering matters, more focused interest in economics and strategic communications, and interest and willingness to engage peers and experts in collaborative and team learning. The items for pre-, mid-, and post-semester surveys on three dimensions and associated constructs (discussed in section 4.3) are presented in Appendix A. In following subsections, scale consistency analysis (section 5.1), study group response analysis (section 5.2), and the differences between the study group and the comparison groups (section 5.3) are discussed based on the pre-semester survey.

5.1 Scale consistency analysis

To assess the internal consistency or reliability of a group of items under each constract, widely used Cronbach's alpha values were calculated (Equation 1) [27]. A value of Cronbach's alpha between 0.7 or above indicates an acceptable level of reliability [28]. However, alpha value over 0.95 does not necessarily indicate good reliability, as it might occur due to the presence of redundancies (i.e., some overlaps in measurement) among the items [29]. For the pre-semester survey data collected from the study group of students (N = 12), Cronbach's alpha value was determined for 14 cases (3rd column in Table 2) to examine the reliability or consistency of a set of items to measure a construct or a dimension (Table 2). In 11 out of 14 cases, the Cronbach's alpha values were found greater than 0.7, which indicates an acceptable reliability or consistency among the items. For the items I_1 and I_2, used to measure the Interdependence construct, Cronbach's alpha = 1, indicating possible redundancies. Items correspond to personal goal setting (PGS_1 to PGS_3), peer feedback (PF_1 to PF_4), and expert feedback (EF_1 to EF_4) provided unacceptable alpha value (0.57, 0.37, and -0.04, respectively). Those items will be revised before mid- and post-semester surveys to improve consistency.

$$\text{Cronbach's alpha value, } \alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} S_i^2}{S_T^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where k= number of items; S_i^2 = variance of item i; S_T^2 = variance of the total scores formed by summing all the items.

Table 2. Test of reliability of quantitative research instrument using pre-survey responses of study group students

Dimension (1)	**Measurement scale (2)**	**Items involved (3)**	**Cronbach's alpha value (4)**
Identification	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	SA_1 to SA_11	0.71
	1- Very low interest, 2- Low interest, 3- Medium interest, 4- High interest, 5- Very high interest	SA_12 to SA_ 13	0.86
	10-point scale where 0 (no confidence) to 9 (complete confidence)	SA_14 to SA_17	0.85
	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	IS_1 to IS_4	0.78

	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	PGS_1 to PGS_3	0.57
	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	SP_1 to SP_3	0.74
Identification (combined constracts)	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	SA_1 to SA_11, IS_1 to IS_4, PGS_1 to PGS_3, SP_1 to SP_3	0.78
Formation	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	RI_1 to RI_3	0.82
	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	T_1 to T_3	0.94
	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	I_1 to I_2	1
	0- None,1- Once, 2- Twice, 3- Three times, 4- More than three times	PF_1 to PF_4	0.37
	0- None,1- Once, 2- Twice, 3- Three times, 4- More than three times	EF_1 to EF_4	-0.04
	0-None,1-Once, 2-Twice, 3- Three times, 4- More than three times	AW_1 to AW_3	0.8
Formation (combined constracts)	1- Strongly disagree, 2- Disagree, 3- Neither agree nor disagree, 4- Agree, 5- Strongly agree	RI_1 to RI_3, T_1 to T_3, I_1 to I_2, PF_7, EF_7	0.81

SA= Self-assessment; IS= Information seeking; PGS= Personal goal setting; SP= Strategic planning; RI= Role identification; T= Trust; I=Interdependence; PF= Peer feedback; EF= Expert feedback; AW= Awareness

5.2 Analysis of study group responses

Descriptive statistics on the responses of the 12 study group students who participated in the pre-semester survey are presented in Appendix B. The normality of each item was tested using skewness and kurtosis statistics. In terms of skewness, responses corresponding to thirty-eight out of forty-nine items showed normal distribution, where responses corresponding to thirty-seven out of forty-nine items showed normal distribution in terms of kurtosis [30].
Study group students strongly understood the need for collaboration with both economics and strategic communication students (M = 4.92, SD = 0.28; M = 4.92, SD = 0.28 respectively).

They also realized the importance of learning economics (*M* = 4.83, *SD = 0.37*) and strategic communication (*M* = 4.75, *SD = 0.43*) skills and tools in the professional development of an engineer. The study group students showed, on average, above "high interest" levels in collaborating with economics (*M* = 4.42, *SD = 0.76*) and strategic communication students (*M* = 4.42, *SD = 0.86*). Analyzing the constructs in the "formation" dimension revealed that the study group showed no statistically significant difference in understanding the role of non-technical students compared to themselves, $p > .05$. In addition, the study group of students showed no significant difference in trust in non-technical students in achieving the multidisciplinary HEPE course outcomes compared to trust in themselves. However, participants in the study group reported that, in the past semesters, they sought nearly zero feedback from non-technical peers and experts for solving problems in a typical engineering course.

5.3 Differences among study group and comparison groups

As explained above, to understand the Holistic Engineering approach's influence on the engineering students (the study group) effectively, two comparison groups of students were selected, where comparison group 1 included 18 students' responses ($N = 18$), and comparison group 2 included 11 students' responses ($N = 11$). Comparison groups were chosen from the same level (junior/senior) of civil engineering courses as the multidisciplinary HEPE. The analysis of variance (ANOVA) was conducted to compare the mean differences in responses of the study group and two comparison groups using the pre-survey data. The estimated p-value and F-value corresponding to nine cases are presented in Table 3. Each case consists of item(s) of a construct measured on the same scale. For six of the nine cases, p-values were found higher than 0.05, thereby indicating no significant difference between responses from the study group and comparison groups. The estimation of F- values also showed the same inference among the study group and comparison groups of students (for six cases, F-values were less than the F-critical value, i.e., 3.24).

Table 3. Results of one-way ANOVA while comparing responses of study and comparison groups

Items compared between study and comparison groups (1)	**p-value (2)**	**F-value (3)**
SA_1 to SA_11	0.01	5.63
SA_12 and SA_13	0.002	6.86
SA_14 to SA_17	0.18	1.82
IS_1 and IS_2	0.28	1.33
SP_1 to SP_3	0.57	0.58
RI_1	0.17	1.86
T_1	0.58	0.55
AW_1 to AW_3	0.23	1.53
U_8	0.01	5.64

SA= Self-assessment; IS= Information seeking; SP= Strategic planning; RI= Role identification; T= Trust; AW= Awareness; U= Understanding

According to the ANOVA results discussed in the last paragraph, only three cases did not support the null hypothesis (p-values were less than 0.05), which revealed that response by at least one student group was different from the remaining two student groups. The standardized t-test was performed to determine which groups of students showed a significant difference in responses for those three cases (Table 4). The t-test p-values corresponding to one of the three cases (case includes items SA_12 and SA_13) revealed that the responses of the study group were significantly different from both comparison groups 1 and 2. Items SA_12 and SA_13 asked about the interest of the students in participating in the multidisciplinary HEPE, and the t-test revealed that the study group was more interested in collaborating with non-technical students compared to both comparison groups 1 and 2. In addition, the study group of students believed that collaboration results in better decisions than working alone, i.e., higher response mean than the comparison groups (Table 4, item U_8), which also might be a reason to prompt them to enroll in the multidisciplinary HEPE. Indeed, as this work was constructed as a field study, students opted in to their course enrollment as is typical in a university setting—as opposed to being randomly assigned to one of the three courses being assessed. Thus, while there are ecological validity benefits of the natural environment context under study, the field design also inherently comes with minimal ability to control extraneous variables. That is, it could be the case that those students who already valued collaboration, for example, could be more likely to sign up for a course entailing collaboration.

Table 4. Results of standardized t-test used to compare three student groups

Items compared between study and comparison groups	Mean (study group/ comparison group 1/ comparison group 2)	Standard deviation(study group/ comparison group 1/ comparison group 2)	p-value		
			Study group and comparison group 1	Study group and comparison group 2	Comparison group 1 and comparison group 2
SA_1 to SA_11	4.43/3.95/4.24	0.32/0.44/0.31	0.004	0.18	0.07
SA_12 and SA_13	4.42/3.17/3.27	0.76/1.01/0.95	0.001	0.01	0.45
U_8	4.58/3.55/4.36	0.64/1.12/0.48	0.009	0.39	0.03

ANOVA results revealed a few statistically significant differences between the study group and the comparison groups pointing to participants' possible differences in a few cases which the researchers will continue to monitor. Nonetheless, the overwhelming majority of similarities across participants at this pre-exposure stage warrant confidence in the benchmark and the potential fruitfulness of mid- and post- semester survey insights for assessing the HEPE model effectiveness. In sum, in spring 2020 semester, a comparison of the HEPE study group pre-survey responses with two comparison groups of engineering students revealed no significant difference among the engineering and comparison groups in the majority of the surveyed constructs.

6. Conclusions

Engineering students need professional skills beyond the traditional technical skills to face complex engineering grand challenges. Generally, this involves a familiarity with major stakeholders and factors in the socio-economic context that both demand and influence engineering expertise and practices. It also involves skills to engage stakeholders in collaborative and multidisciplinary efforts to address the grand challenges of the 21st century. To examine the innovative multidisciplinary approach to holistic engineering education, the National Science Foundation has provided support to West Virginia University to develop and implement the Holistic Engineering Project Experience (HEPE). An initial course has been launched, providing learning opportunities not only for engineering students but students in economics and strategic communications as well. Guided by a faculty team drawn from all three disciplines, students are engaged in shared learning and problem solving as they work to address open-ended, complex, and contemporary transportation engineering challenges. The Cross-Disciplinary Team Learning (CDTL) model consisting of three dimensions (i.e., identification, formation, and adaptation) provides a framework to evaluate and assess learning experiences and outcomes. Now in its initial stages of implementation, the lessons drawn from this initiative can be of broader use to the engineering community and the broader higher education community.

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Appendix A

Table A.1 Items of identification dimension and items assessment period

Construct	Items to be administered	Assessment period

		Pre-survey	Mid-survey	Post-survey
Self-assessment	SA_1_I value reading about topics outside of engineering.	✓	✓	✓
	SA_2_I enjoy thinking about how different fields approach the same problem in different ways.	✓	✓	✓
	SA_3_Not all engineering problems have purely technical solutions.	✓	✓	✓
	SA_4_Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.	✓	✓	✓
	SA_5_I see connections between ideas in engineering and ideas in the economics and strategic communications.	✓	✓	✓
	SA_6_I can take ideas from outside engineering and synthesize them in ways to better understand a problem.	✓	✓	✓
	SA_7_I can use what I have learned in one field in another setting or to solve a new problem.	✓	✓	✓
	SA_8_ I realize the need for collaboration with economics students to achieve the outcomes of this course.	✓	✓	✓
	SA_9_ I realize the need for collaboration with strategic communication students to achieve the outcomes of this course.	✓	✓	✓
	SA_10_ I realize the importance of having economics skills/tools in the professional development of an engineer.	✓	✓	✓
	SA_11_ I realize the importance of having strategic communication skills/tools in the professional development of an engineer.	✓	✓	✓
	SA_12_ I am interested in collaborating with economics students to achieve the outcomes of this course.	✓	✓	✓
	SA_13_ I am interested in collaborating with strategic communication students to achieve the outcomes of this course.	✓	✓	✓

	SA_14_ I am confident to work effectively in a team of multi-disciplinary students.	✓	✓	✓
	SA_15_ I am confident in accomplishing all of the tasks very well with multi-disciplinary students.	✓	✓	✓
	SA_16_ I am confident in accomplishing the outcomes of this Technology Innovation: Engineering, Economics, Public Relations course with multi-disciplinary students.	✓	✓	✓
	SA_17_ I am confident to get good grade in this Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
Information seeking	IS_1_I have gathered information on the scopes and requirements of this Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
	IS_2_I have gathered information on the role of engineering students in this Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
	IS_3_I have gathered information on the role of economics students in this Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
	IS_4_I have gathered information on the role of strategic communication students in this Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
Personal goal setting	PGS_1_Defining personal goals is important to achieve outcomes in a multi-disciplinary course setting**.**	✓	✓	✓
	PGS_2_ I set personal goals for this course.	✓	✓	✓
	PGS_3_ Personal goal setting in a multidisciplinary course is different compared to the personal goal setting in engineering courses.	✓	✓	✓
Strategic planning	SP_1_I have clearly defined steps to achieve personal goals in this course.	✓	✓	✓
	SP_2_ I have clearly defined steps to achieve course goals.	✓	✓	✓
	SP_3_ I spend time to identify effective communication strategies to work in the multi-disciplinary team.	✓	✓	✓

Self-monitoring	SM_1_I apply engineering discipline related knowledge and skills in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	SM_2_ I frequently monitor my contribution to the team performance in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	SM_3_ I frequently monitor my activities to ensure that they will lead to satisfying the defined course scopes and outcomes		✓	✓

Table A.2 Items of formation dimension and items assessment period

Construct	**Items to be administered**	**Assessment period**		
		Pre-survey	**Mid-survey**	**Post-survey**
Team goal setting	TG_1_The team goals of this course are clear.		✓	✓
	TG_2_The team goals are appropriate to achieve the course outcomes.		✓	✓
	TG_3_The team goals are well defined considering the background and potential of team members.		✓	✓
	TG_4_The team goals will help me to accomplish most of the personal goals I have set for myself.		✓	✓
Role Identification	RI_1_I completely understand the role of engineering students in this multi-disciplinary Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
	RI_2_I completely understand the role of economics students in this multi-disciplinary Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓
	RI_3_ I completely understand the role of strategic communication students in this multi-disciplinary Technology Innovation: Engineering, Economics, Public Relations course.	✓	✓	✓

Trust	T_1_ I trust the other engineering students in my team in achieving the course outcomes.	✓	✓	✓
	T_2_ I trust the economics students in my team in achieving the course outcomes.	✓	✓	✓
	T_3_ I trust the strategic communication students in my team in achieving the course outcomes.	✓	✓	✓
	T_4_ Team members communicate their specific disciplinary perspectives effectively in achieving the outcomes of this course.		✓	✓
Interdependence	I_1_ Engineering students need economics skills/tools to solve multi-disciplinary engineering problems.	✓	✓	✓
	I_2_ Engineering students need strategic communication skills/tools to solve multi-disciplinary engineering problems.	✓	✓	✓
	I_3_I found that team members were dependent on each other.		✓	✓
	I_4_The team members benefitted from their dependencies on one another.		✓	✓
	I_5_The team members dependencies hindered progress.		✓	✓
Peer feedback	PF_1_I sought feedback from engineering students for solving problems in a typical engineering course.	✓		
	PF_2_I sought feedback from economics students for solving problems in a typical engineering course.	✓		
	PF_3_I sought feedback from strategic communication students for solving problems in a typical engineering course.	✓		
	PF_4_ I sought feedback from students of other disciplines for solving problems in a typical engineering course.	✓		
	PF_5_I sought feedback from engineering students for solving problems in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓

	PF_6_ I sought feedback from economics students for solving problems in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	PF_7_ I sought feedback from strategic communication students for solving problems in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	PF_8_I found peer feedback to be extremely helpful in solving problems in most engineering courses.	✓		
	PF_9_ I found peer feedback to be extremely useful in achieving the outcomes of this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	PF_10_I preferred expert feedback (e.g., professors) compared to peer feedback in multi-disciplinary team learning.		✓	✓
Expert feedback	EF_1_I sought feedback from experts (e.g., professors) in engineering field for solving problems in a typical engineering course.	✓		
	EF_2_I sought feedback from experts (e.g., professors) in economics field for solving problems in a typical engineering course.	✓		
	EF_3_I sought feedback from experts (e.g., professors) in strategic communication field for solving problems in a typical engineering course.	✓		
	EF_4_ I sought feedback from experts (e.g., professors) in other disciplines for solving problems in a typical engineering course.	✓		
	EF_5_ I sought feedback from experts (e.g., professors) in engineering discipline for solving problems in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	EF_6_I sought feedback from experts (e.g., professors) in economics discipline for solving problems in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓

	EF_7_I sought feedback from experts (e.g., professors) in strategic communication discipline for solving problems in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	EF_8_ I found expert feedback to be extremely helpful in solving problems in most engineering courses.	✓		
	EF_9_ I found expert feedback to be extremely helpful in achieving the outcomes of this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
Awareness	AW_1_I am aware of the economics learning outcomes.	✓	✓	✓
	AW_2_I am aware of the strategic communications learning outcomes.	✓	✓	✓
	AW_3_ Awareness of other discipline's learning outcomes help engineers to understand the role of other disciplines in solving engineering problems.	✓	✓	✓
Appreciation	AP_1_ I appreciate ideas proposed by economics students in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	AP_2_ I appreciate ideas proposed by strategic communication students in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓
	AP_3_ I ask relevant questions to communicate with cross-disciplinary team members in this Technology Innovation: Engineering, Economics, Public Relations course.		✓	✓

Table A.3 Items of adaptation dimension and items assessment period

Construct	Items to be administered	Assessment period		
		Pre-survey	**Mid-survey**	**Post-survey**
Goal alignment	GA_1_Team members worked together to achieve our collective team goals.		✓	✓

	GA_2_ When our goals were not aligned at the beginning of the semester, we had the most conflicts.		✓	✓
	GA_3_ Over the course of the semester, the goals became less driven by individual disciplines and more driven by the team's collective goals.		✓	✓
	GA_4_ I adapted my personal goals to meet team goals.		✓	✓
Shared mental models	SMM_1_ In my team, team members regularly seek information and other resources from each other.		✓	✓
	SMM_2_ In my team, team members monitor each other's efforts.		✓	✓
	SMM_3_ In my team, team members influence each other's reasoning and behavior.		✓	✓
	SMM_4_ In my team, team members provide immediate feedback on each other's performance.		✓	✓
	SMM_5_ Value of knowledge of economics in solving multi-disciplinary problem became more evident over the course of the semester.		✓	✓
	SMM_6_ Value of knowledge of strategic communications in solving multi-disciplinary problem became more evident over the course of the semester.		✓	✓
	SMM_7_ To achieve course outcome, team effort became more noticeable than individual effort over the course of the semester.		✓	✓
Understanding	U_1_ As the course progressed, I used language and concepts of economics more frequently to meet course requirements.		✓	✓
	U_2_ As the course progressed, I used language and concepts of strategic communications more frequently to meet course requirements.		✓	✓
	U_3_ My interactions with the economics students on my team helped me to develop a better understanding of their discipline.		✓	✓

	U_4_ My interactions with the economics students on my team helped me to develop a greater appreciation for their discipline.		✓	✓
	U_5_ My interactions with the strategic communication students on my team helped me to develop a better understanding of their discipline.		✓	✓
	U_6_ My interactions with the strategic communication students on my team helped me to develop a greater appreciation for their discipline.		✓	✓
	U_7_ As the course progressed, I became more proactive and started providing strategic communication perspectives on issues before it was requested.		✓	✓
	U_8_ People who work collaboratively in teams make better decisions than those who work individually.	✓	✓	✓

Appendix B

Table B.1 Descriptive statistics corresponding to the responses of study group of students

Item administered	Mean	Standard deviation	Skewness	Kurtosis
SA_1_I value reading about topics outside of engineering.	4.50	0.50	0.00	-2.44^{+}
SA_2_I enjoy thinking about how different fields approach the same problem in different ways.	4.25	0.43	1.15*	-0.33
SA_3_Not all engineering problems have purely technical solutions.	4.33	0.62	-0.38	-0.34
SA_4_Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.	4.33	0.62	-0.38	-0.34
SA_5_I see connections between ideas in engineering and ideas in the economics and strategic communications.	4.08	1.11	-0.89	-0.32

SA_6_I can take ideas from outside engineering and synthesize them in ways to better understand a problem.	4.25	0.60	-0.15	-0.09
SA_7_I can use what I have learned in one field in another setting or to solve a new problem.	4.50	0.50	0.00	-2.44^{+}
SA_8_ I realize the need for collaboration with economics students to achieve the outcomes of this course.	4.92	0.28	-3.02*	12.00^{+}
SA_9_ I realize the need for collaboration with strategic communication students to achieve the outcomes of this course.	4.92	0.28	-3.02*	12.00^{+}
SA_10_ I realize the importance of having economics skills/tools in the professional development of an engineer.	4.83	0.37	-1.79*	2.64^{+}
SA_11_ I realize the importance of having strategic communication skills/tools in the professional development of an engineer.	4.75	0.43	-1.15*	-0.33
SA_12_ I am interested in collaborating with economics students to achieve the outcomes of this course.	4.42	0.76	-0.86	-0.46
SA_13_ I am interested in collaborating with strategic communication students to achieve the outcomes of this course.	4.42	0.86	-1.69*	4.37^{+}
SA_14_ I am confident to work effectively in a team of multi-disciplinary students.	7.75	1.16	-0.77	0.89
SA_15_ I am confident in accomplishing all of the tasks very well with multi-disciplinary students.	7.83	0.90	0.33	-1.93
SA_16_ I am confident in accomplishing the outcomes of this Technology Innovation: Engineering, Economics, Public Relations course with multi-disciplinary students.	7.92	1.04	-0.28	-1.38
SA_17_ I am confident to get good grade in this Technology Innovation: Engineering, Economics, Public Relations course.	8.25	0.60	-0.15	-0.09

IS_1_I have gathered information on the scopes and requirements of this Technology Innovation: Engineering, Economics, Public Relations course.	3.83	0.80	-0.67	1.15
IS_2_I have gathered information on the role of engineering students in this Technology Innovation: Engineering, Economics, Public Relations course.	3.92	0.76	0.14	-1.26
IS_3_I have gathered information on the role of economics students in this Technology Innovation: Engineering, Economics, Public Relations course.	3.33	0.94	-0.11	-0.98
IS_4_I have gathered information on the role of strategic communication students in this Technology Innovation: Engineering, Economics, Public Relations course.	3.50	0.87	-0.38	-0.33
PGS_1_Defining personal goals is important to achieve outcomes in a multi-disciplinary course setting.	4.33	0.47	0.71	-1.65
PGS_2_ I set personal goals for this course.	4.50	0.50	0.00	-2.44^{+}
PGS_3_ Personal goal setting in a multidisciplinary course is different compared to the personal goal setting in engineering courses.	4.00	1.08	-0.79	-0.34
SP_1_I have clearly defined steps to achieve personal goals in this course.	3.50	0.96	0.00	-0.76
SP_2_ I have clearly defined steps to achieve course goals.	3.83	0.90	-0.36	-0.30
SP_3_ I spend time to identify effective communication strategies to work in the multi-disciplinary team.	3.92	0.76	0.14	-1.26
RI_1_I completely understand the role of engineering students in this multi-disciplinary Technology Innovation: Engineering, Economics, Public Relations course.	4.08	0.76	-0.14	-1.26

RI_2_I completely understand the role of economics students in this multi-disciplinary Technology Innovation: Engineering, Economics, Public Relations course.	3.67	0.85	-0.12	-0.25
RI_3_ I completely understand the role of strategic communication students in this multi-disciplinary Technology Innovation: Engineering, Economics, Public Relations course.	4.00	0.82	0.00	-1.65
T_1_ I trust the other engineering students in my team in achieving the course outcomes.	3.83	0.99	-1.75*	5.58^{+}
T_2_ I trust the economics students in my team in achieving the course outcomes.	3.83	0.80	-0.67	1.15
T_3_ I trust the strategic communication students in my team in achieving the course outcomes.	3.92	0.64	0.08	-0.19
I_1_Engineering students need economics skills/tools to solve multi-disciplinary engineering problems.	4.42	0.64	-0.64	-0.19
I_2_Engineering students need strategic communication skills/tools to solve multi-disciplinary engineering problems.	4.42	0.64	-0.64	-0.19
PF_1_I sought feedback from engineering students for solving problems in a typical engineering course.	3.25	1.16	-1.76*	4.36^{+}
PF_2_I sought feedback from economics students for solving problems in a typical engineering course.	0.17	0.55	3.02*	12.00^{+}
PF_3_I sought feedback from strategic communication students for solving problems in a typical engineering course.	0.08	0.28	3.02*	12.00^{+}
PF_4_ I sought feedback from students of other disciplines for solving problems in a typical engineering course.	1.25	1.42	0.95	0.09

PF_8_I found peer feedback to be extremely helpful in solving problems in most engineering courses.	4.00	0.82	0.00	-1.65
EF_1_I sought feedback from experts (e.g., professors) in engineering field for solving problems in a typical engineering course.	2.58	1.55	-0.49	-1.30
EF_2_I sought feedback from experts (e.g., professors) in economics for solving problems in a typical engineering course.	0.00	0.00	N/A	N/A
EF_3_I sought feedback from experts (e.g., professors) in strategic communication field for solving problems in a typical engineering course.	0.00	0.00	N/A	N/A
EF_4_ I sought feedback from experts (e.g., professors) in other disciplines for solving problems in a typical engineering course.	0.50	0.50	0.00	-2.44⁺
EF_8_ I found expert feedback to be extremely helpful in solving problems in most engineering courses.	4.08	0.76	-0.14	-1.26
AW_1_I am aware of the economics learning outcomes.	3.58	1.19	-0.35	1.65
AW_2_I am aware of the strategic communications learning outcomes.	2.92	1.11	0.16	-0.67
AW_3_ Awareness of other discipline's learning outcomes help engineers to understand the role of other disciplines in solving engineering problems.	3.75	1.42	-0.08	-0.10
U_8_ People who work collaboratively in teams make better decisions than those who work individually.	4.58	0.64	-1.27*	1.39

*The distribution is skewed. ⁺ The distribution is kurtotic.