Enhancing Transdisciplinary Learning through Community-Based Design Projects: Results from a Mixed Methods Study

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Abstract – To address complex sustainability challenges, solutions are needed that integrate the biophysical and sociocultural dimensions of sustainability. Engineers designing these solutions must be technically adept problem solvers, as well as effective at integrating the non-technical dimensions of sustainability into their design solutions. This paper reports on educational interventions in both a university engineering course and engineering service-learning skill sessions. Using a mixed methods assessment approach to investigate the interventions, data were collected using a variety of instruments and analyzed using thematic analysis and appropriate statistical tests. Our findings include an increase in students' awareness and understanding of non-technical dimensions in design, and suggest that a transdisciplinary knowledge production model may enhance students' abilities to integrate non-technical dimensions, as well as engage with stakeholders, in community-based design projects. This study advances understanding of appropriate learning environments, teaching methods, and assessment tools for developing engineering competencies in sustainability problem solving.

Index Terms - Transdisciplinary, design, sustainability

INTRODUCTION

The world is faced with highly complex sustainability challenges. With increased recognition of the coupling of human and natural systems, emergent issues from these interconnections are putting additional stress on the planet and threatening sustainability. These socio-environmental issues transcend boundaries—spatial, temporal, sector, and disciplinary—and affect a variety of interest groups, thereby engaging diverse values, interests, and priorities.^{1 2} Solutions are needed to integrate the biophysical and sociocultural dimensions of sustainability.^{3 4 5} Engineers designing these solutions must be technically adept problem solvers and also effective at integrating the non-technical dimensions of sustainability into their design solutions.

Addressing today's sustainability challenges thus requires transdisciplinary collaboration across disciplinary boundaries, as well as among experts in industry, economics, politics, planning, and beyond. In these collaborative spaces, researchers have also suggested a specific set of needed competencies: *systems-thinking* competence, *anticipatory* competence, *normative* competence, *strategic* competence, and *interpersonal* competence.⁶ These competencies go beyond the

traditional skill set of technically competent engineers. Future practicing engineers must also be able to understand the broader impact of sustainable design solutions, and be able to engage and collaborate across boundaries.^{7 8 9 10 11 12}

In recent years, scholars have recommended educational experiences for engineering students that aim to improve their understanding of the relationships between the environmental, social, political, and economic spheres of sustainability and how they affect design solutions.^{13 14 15} ABET¹⁶ similarly states that engineering graduates should possess a broader set of professional skills including the understanding of the impact of engineering solutions in a global, economic, environmental and societal context (ABET outcome 3h) and awareness of sustainability as a salient consideration when designing a system, component, or process (ABET outcome 3c). Environmental and professional organizations and accrediting agencies have also called for education in the area of sustainability to develop students' awareness and competencies toward creating a more sustainable future.^{17 18}

This manuscript reports on an educational intervention in transdisciplinary learning and advances understanding of appropriate learning environments, teaching methods, and assessment tools for developing engineering competencies in sustainability problem solving. The paper begins with a literature review of such competencies, as well as a discussion of transdisciplinary knowledge production models and appropriate learning environments. Our findings are then presented along with implications for future work. Lessons learned and materials developed through this research are especially applicable to those in higher education, and specifically individuals teaching engineering students engaged in community-based design projects.

LITERATURE REVIEW

Developing competencies in sustainability problem solving represents a significant challenge to higher education. Engineering education has traditionally focused on technical problem solving, often without considering the associated social, political, and economic dimensions.^{19 20} Engineering students have historically been taught to draw boundaries that lead to right or wrong answers.^{21 22} This contrasts to ways of knowing in the humanities and social sciences, which often thrive upon contributions to a broader conversation rather than claiming absolute truths.²³ Still others have argued that being able to integrate and synthesize knowledge is a key competency for engineers.^{24 25} More traditional engineering approaches, which tend to exclude non-technical dimensions in the problem solving and the design process, can distort problem definition and lead to inappropriate solutions for target uses and partner communities.²⁶

To complement traditional engineering approaches, contemporary reforms to engineering education have integrated more design content into curricula and shifted to more open-ended and indeterminate problem solving.^{27 28} With a few notable exceptions, however, these reforms have not sufficiently addressed the non-technical dimensions of collaborative problem solving,²⁹ and relatively little has changed in the kinds of engineering curricula that dominate the academic landscape.³⁰ While while most current engineering programs intersperse humanities and social sciences coursework throughout the degree program in an attempt to address ABET outcome 3h and broader university-wide general education requirements, this curricular model only tends to reinforce the dichotomy between engineering's technical core and its non-technical periphery.³¹ Ultimately, wider and deeper reforms are needed in engineering education, including revision of

courses and curricula to include the non-technical dimensions of design and prepare engineering graduates for the sustainability challenges of the 21st century.^{32 33 34}

Transdisciplinary Models for Increasing Engineering Competencies

In order to address complex sustainability problems, effective project design strategies for engineers will require a significant shift from traditional business-as-usual approaches in knowledge creation toward more socially engaged, context-sensitive, and transdisciplinary approaches. Transdisciplinary approaches to knowledge production can better account for the complexity of natural and human-made environments.^{35 36 37 38 39 40} Such approaches go beyond traditional multidisciplinary and interdisciplinary problem-solving frameworks within academia to link together scientists, practitioners, and stakeholders, thereby enabling connections between multiple ways of interpreting the world while enhancing collaboration across traditional knowledge-production boundaries (Figure 1).^{41 42 43} Transdisciplinary knowledge production can be an effective tool for engaging all actors in environments where physical, social, technical, and economic sectors interact with culture and values, such as in community-based engineering sustainable design projects.^{44 45} Transdisciplinary knowledge has the potential to not only address the multifaceted complexities of the engineering design process occurring between multiple stakeholders, but also provide a model for integrating non-technical dimensions into design solutions.

FIGURE 1
MULTIDISCIPLINARY, INTERDISCIPLINARY, AND TRANSDISCIPLINARY PROBLEM-SOLVING
FRAMEWORKS (MODIFIED FROM BORREGO AND NEWSWANDER⁴⁶).

While there has been work in integrating transdisciplinary knowledge production frameworks into various areas of sustainability and engineering—e.g., groundwater management, energy resources analysis, sustainable supply chain management^{47 48 49 50}—efforts have largely been focused upon using these frameworks for research rather than as curricular interventions. Additionally, Remington-Doucette et al.⁵¹ found that “despite the apparent benefits and widespread advocacy for interdisciplinary and transdisciplinary programs [in higher education], the success of these programs in fostering students’ capacities for real-world problem solving

remains unsubstantiated.” In other words, little work has been done to document and assess transdisciplinary-focused curricular interventions in the classroom setting.

To further complicate matters, the majority of the related literature in engineering education refers to transdisciplinary knowledge as thinking or working across academic disciplines, but excluding knowledge and knowledge production processes outside of academia.^{52 53 54 55 56} While research has demonstrated how such approaches can improve the ability of students to integrate diverse perspectives and tools from academic disciplines, potentially relevant perspectives and knowledge production tools from outside of academia often remain marginal or invisible.^{57 58 59 60} As multiple scholars have argued,^{61 62 63} completing the transdisciplinary knowledge production loop requires integration efforts that transcend the academic sphere.

Appropriate Learning Environments

While transdisciplinary knowledge production models may offer frameworks for problem solving to increase students’ awareness of non-technical dimensions of design, specific learning environments are also needed to effectively integrate these dimensions into sustainable design solutions. For instance, Steinemann⁶⁴ calls for education for sustainability that integrates interactive, experiential, transformative, and real-world learning experiences. Scholars suggest that such experiences might include: active learning, cooperative learning, and real-world experiences that offer a valuable service for communities without reducing the academic content.⁶⁵ ⁶⁶ These experiential, hands-on design experiences can build confidence in engineering design skills.⁶⁷ They can also increase sustainability competencies by linking knowledge with action in problem solving; increasing awareness of values, politics, and resources in negotiated problem solving processes; and providing exposure to meaningful collaboration.^{68 69}

Experiential learning strategies, such as problem-/project-based learning (PBL) and service-learning, have demonstrated success in developing professional engineering competencies. In PBL, students learn about a subject through the experience of solving an authentic, open-ended problem in ways that encourage and nurture deep, active learning.^{70 71 72} For example, Secundo et al.⁷³ found that PBL strategies embedded in cooperative partnerships with academia and industry in a manufacturing engineering courses are most suitable for developing engineering competencies, both technical and professional. In computer engineering, students participating in a project-based active and collaborative learning environment similarly demonstrated enhanced teamwork and communication skills.⁷⁴

Service-learning, on the other hand, offers credit-bearing, educational opportunities in which students participate in and reflect upon an organized service activity that meets an identified community need while simultaneously increasing understanding of the academic concepts being taught.^{75 76} Using service-learning as a pedagogical strategy in engineering to help prepare students to engage in real world contexts has received increasing attention among educators,^{77 78 79 80} as reflected in a growing number of engineering courses that now include service-learning as a method to increase awareness and understanding of professional skills and other non-technical dimensions of engineering practice, i.e., ABET 3.g, 3.h, and 3.j.^{81 82 83 84 85 86 87}

The service-learning model may be a particularly promising approach that is especially well-suited to promoting competency in integrating non-technical dimensions of sustainability into design solutions. This pedagogical strategy has been shown to promote engagement and collaboration with partners outside of academia.^{88 89 90} Further, other scholars have demonstrated

that students can develop a deep understanding of the impact of technical engineering solutions in the environmental and societal context, especially by reflecting on their service-learning experiences and recognizing that their efforts will lead to concrete results in the real world.^{91 92} Additionally, Coyle et al.⁹³ and Al-Khafaji and Morse⁹⁴ noted the development of non-technical skills, e.g., sustainability awareness, cultural sensitivity, and teamwork, increased after service-learning experiences. Significant increases in sustainability problem-solving competencies can also occur when using service-learning as a pedagogical tool. For example, Al-Khafaji and Morse⁹⁵ found that service-learning provided opportunities to integrate social and other non-technical dimensions of engineering design into the curriculum, whereas Clevenger and Ozbek⁹⁶ found that service-learning. Additionally, Hayden et al.⁹⁷ observed that service-learning influences students' understanding of the roles and responsibilities of engineers in society.

By combining the two pedagogical strategies—PBL and service-learning—together with a transdisciplinary knowledge production model, this research was designed to directly address the need for engineering students to be able to integrate non-technical dimensions into their community-based design solutions, thus increasing their competencies in sustainability problem solving. Ultimately, this study further advances our understanding of appropriate learning environments and teaching methods, as well as assessment tools for developing such competencies.

METHODS

To build upon prior research and explore how transdisciplinary learning in community-based design projects, as well as affect their sustainability problem-solving competencies, a case study of teaching and learning in an upper-level environmental and ecological engineering service-learning community-based design course (EEE 495) was conducted in the spring of 2014. A case study approach is an appropriate research design for such an investigation because: 1) the nature of the research question is typically explanatory, exploratory, or descriptive; 2) the investigator lacks methods to control the site and participants; and 3) the phenomenon being studied is contemporary and the context is real life.⁹⁸ A second, condensed intervention was also conducted in two Engineering Projects in Community Service (EPICS) lecture skill sessions in spring of 2014. EPICS is a service-learning design program in which teams of students partner with local and global community organizations to address human, community, and environmental needs. The lead author taught the course and served as the primary instrument for data collection and analysis with the second author. To increase objectivity and transparency, as well as mitigate against biases in the study the researchers followed appropriate protocol, specifically utilizing a third researcher to conduct the interviews.

The specific research questions that guided this study were:

- RQ1: How does a transdisciplinary knowledge production model for decision making affect students' awareness of, understanding of, and ability to apply non-technical dimensions into community-based design projects?
- RQ2: How does a transdisciplinary knowledge production model for decision making affect students' sustainability problem-solving competencies?

Research Context

Since local environmental issues are inherently linked to multiple dimensions of sustainability and involve a multitude of stakeholders' values, interests, and opinions, they serve as appropriate design opportunities for educators seeking to increase students' professional engineering and sustainability competencies. Additionally, the accessibility of the project site, as well as the opportunity to address an immediate community need in a relatively short time frame, makes it a fitting learning environment for the first of two interventions studied here. The first, a three-credit, semester-long, elective, interdisciplinary environmental and ecological engineering course at a large, Midwestern research-intensive university introduced a specific environmental issue, namely by focusing on an unhealthy local river with stormwater runoff problems, coupled with small-scale best management practices in remediation, i.e., rain gardens, rain barrels, pervious pavement, and native savannas. In partnership with two local non-profits, a local business, and an industry funder, students were tasked with identifying stormwater management issues, designing small-scale technical solutions, maintaining budgets, and evaluating impacts with a local middle school. In this real-world, service-learning context, students were taught about the complex and dynamic relationships between social, economic, environmental, and political dimensions in sustainable community-based design projects, as well as how to use a transdisciplinary knowledge production model in design (Figure 2).

FIGURE 2

TRANSDISCIPLINARY KNOWLEDGE PRODUCTION MODEL FOR SUSTAINABLE COMMUNITY-BASED DESIGN.⁹⁹

The transdisciplinary knowledge production model was developed based upon a literature review analyzing the discourse of transdisciplinary knowledge across academic disciplines in regards to actors and interactions involved in the transdisciplinary knowledge production process.¹⁰⁰ The specific learning outcomes and objectives for the course were aligned with this framework and research questions (Table 1). Course activities and assessments outlined in the syllabus included: lectures; readings; team facilitation and critical reflection assignments; group

presentations and proposals; design charrettes; stakeholder feedback sessions; and self- and peer-evaluations. All activities were structured to provide students with opportunities to develop an increased awareness of, understanding of, and ability to apply non-technical dimensions into community-based design projects by using a transdisciplinary knowledge production model for decision making, thus enhancing sustainability problem-solving competencies.

TABLE 1
LEARNING OUTCOMES FOR ENVIRONMENTAL AND ECOLOGICAL ENGINEERING: URBAN WATER
PROJECTS (EEE 495) MAPPED TO RESEARCH QUESTIONS.

Learning Outcomes	Research Questions*
<i>Students will be able to:</i>	
1. Design novel, context-appropriate solutions to local stormwater sustainability issues using a transdisciplinary knowledge production model.	
a. Describe the interconnectivity between environmental, social, political, and economic issues surrounding technical solutions.	RQ1
b. Apply a transdisciplinary knowledge production model.	RQ1
c. Propose solutions to open-ended design problems that demonstrate a deep comprehension of the issues.	RQ2
<i>Students will be able to:</i>	
2. Engage in the complexities of a negotiated design process occurring between multiple stakeholders in a professional and ethical manner.	
a. Demonstrate empathy and adaptability in working with teammates and stakeholders with varied skills, talents, abilities, and work strategies.	--
b. Create project deliverables that demonstrate cohesive stakeholder functionality.	RQ2
c. Critically evaluate personal and others' contributions to the overall success of the projects.	--
<i>Students will be able to</i>	
3. Display social responsibility, civic engagement, and leadership in addressing local water sustainability issues.	
a. Evaluate and apply diverse perspectives from multiple stakeholders.	RQ1, RQ2
b. Connect and extend academic knowledge to civic engagement.	--
c. Take informed, responsible action to address ethical, social, and environmental challenges.	RQ2
d. Communicate project efforts in a creative, well-organized, and logical manner.	--

*Note: the focus of the study design and intervention was on investigating RQ1, then conclusions were drawn relative to RQ2 based upon these results.

The second intervention, the forty-five minute EPICS skill session, consisted of a short lecture and small group discussion designed to increase participants' awareness and understanding of non-technical dimensions in community-based design projects. EPICS skills sessions are specialized lecture supplements that provide opportunities for EPICS students to gain expertise needed for projects and broaden their experience.¹⁰¹

Participant Demographics

Fifteen students completed the EEE 495 course representing the following majors: environmental and ecological engineering (12 students), political science (1), natural resources and environmental science (1), and landscape architecture (1). The majority of the students were juniors (10 students), along with three seniors, one sophomore, and one freshman. There were seven participants who identified as female and eight as male. Five of the students reported having some sort of prior design experience; however, none of those experiences involved direct contact with users during all stages of the project, making the design experience in this course very distinct from previous exposure.

A total of twenty-five students completed the two EPICS skill sessions, representing the following majors: agricultural and biological engineering (1 student), agronomy (1), biological engineering (1), chemistry (1), computer engineering (1), electrical and computer engineering (1), electrical engineering (4), first year (4), industrial engineering (1), mechanical engineering (3), mechanical engineering technology (1), statistics (1), and (5) unknown/not specified. Of the students, seven were seniors, four were juniors, six were sophomores, and three were first-year. There were eight participants who self-identified as female and eleven as male. For completing all study procedures, participating students in EEE 495 received 1% extra credit toward their overall course grade. EPICS student participants satisfied a course requirement by attending the skill session.

Data Collection and Analysis

Data collection methods were selected to provide multiple sources of evidence for triangulation, or a convergence of results, and a rich description of the intervention.^{102 103} As certain methods are appropriate for specific situations, mixing methods can help capitalize on the advantages of both qualitative and quantitative approaches, including by reducing biases associated with overreliance on specific data sources and methods.^{104 105} Using a convergent parallel design in this study, both quantitative and qualitative data were collected and analyzed at the same time. The results were then merged to form an overall interpretation of the educational intervention. Following Yin's¹⁰⁶ protocol for case study research, a database for data management was developed, as well as documentation of a detailed, complete chain of evidence available for review by external observers.

All quantitative data was collected and subjected to statistical analyses when appropriate, whereas the qualitative data was transcribed, coded, and analyzed to identify common themes and draw inferences, and lastly subjected to statistical analyses when appropriate. To interpret the raw material for the qualitative data, thematic analysis was used to inductively transform qualitative information into quantitative data.¹⁰⁷ Emergent themes were identified and then all data was

recoded and grouped according to the dominant themes. Following standard open-coding procedures, a detailed code book and inter-raters were used to verify results.¹⁰⁸

It is additionally important to note that the intent of this study is to form a unique interpretation of events, not to generalize findings. The uniqueness of the specific context in which the study is occurring mitigates against replicating the intervention and study in exactly the same context; however, transferability and replication in other settings is potentially enhanced through transparency in describing central assumptions, selection of the informants, and the biases and values of researcher. As Yin¹⁰⁹ recommends, we also report detailed protocols for data collection.¹¹⁰ Appropriate permission for conducting this study was approved by Purdue University's Institutional Review Board (protocol #1312014361), and all names and institutions referenced in the manuscript are pseudonyms to protect participants' identities.

Data Collection Instruments

Assessment instruments used in traditional educational settings often include the evaluation of student work, rubrics for learning objectives, and surveys;¹¹¹ however, these data sources are often unsuitable for experiential learning as students need to time to reflect on and think deeply about their experiences.¹¹² Service-learning scholars additionally suggest critical reflection, observation, interviews, cumulative portfolios, and post-experience surveys to address this issue.^{113 114} Table 2 provides a summary of the data collection instruments used in this study and associated analysis approaches, and the text below provides an expanded description of each instrument and specific areas of measurement. Data collection instruments were developed based upon an earlier offering of the course in spring 2013 and previous assessment work by Jesiek and Woo¹¹⁵ and Jesiek, Haller, and Thompson.¹¹⁶ Instruments were piloted among content experts and former students in the course and revised for clarification via a series of iterative feedback and discussion sessions.

TABLE 2
 SUMMARY OF DATA COLLECTION INSTRUMENTS, ASSOCIATED DATA, ANALYSIS APPROACH, AND
 SUBJECTS (SEE APPENDICES A, B, & C FOR COMPLETE INSTRUMENTS).

Instrument	Data	Analysis Approach	Subjects
Pre/Post Interviews	Semi-structured	Thematic analysis	EEE 495 Students (N = 5)
Pre/Post Assessment Survey	Forced-response and open-ended questions addressing students' awareness, understanding, and ability to apply non-technical dimensions and transdisciplinary knowledge production models	Thematic analysis Statistical tests	EEE 495 Students (N = 15) EPICS Students (N = 25)

Pre/Post Reflection	Semi-structured open-ended questions addressing students' awareness, understanding, and ability to apply non-technical dimensions and transdisciplinary knowledge production models	Thematic analysis	EEE 495 Students (N = 15)
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Interviews

The use of semi-structured interviews (Appendix A) offers a method for pursuing a consistent line of inquiry among participants, while also allowing the interviewer to probe more deeply, seek clarification of respondent's interpretations, and corroborate findings from other data collection instruments.^{117 118} For this study, interview participants were selected from the EEE 495 course based upon their performance on a pre-course assessment survey, e.g., by examining how many non-technical dimensions each student was able to identify in response to a pre-course survey prompt. One high-performing male, two high-performing females, two low-performing males, and one low-performing female were selected to represent multiple viewpoints of the study population. Pre/post interviews were conducted with all six participants; however, one high-performing female did not participate in her post-course interview, and thus her results are not represented in the final analysis. The raw data from the interviews was thematically analyzed for *considerations* included in the design process with a 90% agreement in inter-rater reliability using Cohen's kappa, and then recoded using a rubric adapted from Mazzurco, Huff, and Jesiek,¹¹⁹ which includes four categories of considerations: stakeholder considerations, technical considerations, non-technical constraints, and broader considerations (Figure 3).

FIGURE 3
CODING HIERARCHY FOR CONSIDERATIONS WITH EXAMPLE CODED ITEMS (ADAPTED FROM MAZZURCO, HUFF, AND JESIEK¹²⁰).

Coding for design considerations was intended to measure awareness of, understanding of, and ability to apply non-technical dimensions to community-based design projects. Thematic analysis was also used to inductively code the raw data for *actors* and *interactions* involved in the knowledge production process with respective agreements in inter-rater reliability of 94% and 87%. Since the final rubrics used to recode the raw data emerged during the data analysis, they will be discussed in more detail in the results section. Coding for actors and interactions measures

awareness, understanding, and ability to apply a transdisciplinary knowledge production model in community-based design projects. Coding for actors provided insight into individuals that are included and/or excluded in transdisciplinary knowledge production, whereas coding for interactions offered an overview of processes and methods used by students in transdisciplinary knowledge production. Descriptions of each overarching construct and an excerpt of coded text for each measure are listed below in Table 3.

TABLE 3
DESCRIPTIONS OF EACH OVERARCHING CODE FOR EACH CONSTRUCT AND AN EXCERPT OF CODED TEXT FOR EACH MEASURE FROM INTERVIEW DATA.*

Considerations	
Definition	Includes items, things, considerations (stakeholder, technical, non-technical, broader) to be thought about or considered during the design process
Example excerpt used for coding “considerations”	“...you have to consider <u>people</u> , <u>investors</u> , you have to consider <u>schools</u> , <u>kids</u> , <u>their wants</u> , <u>needs</u> . You have to consider the <u>natural aspect of where you are trying to implement these designs</u> and <u>how it is going to affect the landscape</u> and <u>how much we will conserve</u> .”
Actors	
Definition	Includes individuals/groups involved in knowledge production and decision making through actionable engagement, i.e. questioning, collaborating, designing
Example excerpt used for coding “actors”	“ <u>Us in academia</u> that includes the <u>students</u> and the <u>instructors</u> . You have <u>professional engineers</u> , <u>contractors</u> , <u>people who actually do this work out in the field</u> . <u>Teachers</u> and <u>students</u> at the school and <u>maintenance workers</u> , <u>people at the building who are directly affected</u> . <u>People who are indirectly affected</u> , <u>people who drive by</u> , <u>the parents</u> , the <u>English teachers</u> who see it but are not going to teach their <u>kids</u> about is necessarily.”
Interactions	
Definition	includes an action or process involved in knowledge production or toward the achievement of transdisciplinary knowledge
Example excerpt used for coding “interactions”	“... <u>communication</u> , <u>talking</u> , <u>physically talking</u> , <u>whatever method of communication you get to actually interact with the other stakeholders involved</u> . That is the biggest one. Just really openness, the willingness to <u>offer feedback to share opinions</u> to <u>think collaboratively with other people</u> .”

*Underlined instances designate coded text.

Assessment Surveys

The assessment survey (Appendix B) included an open-ended, rank order scenario prompt (questions #2-3) and two forced-choice response, rank-order prompts (#4, 12) for design considerations, as well as Likert scale measures (#5-11, 13-19) for understanding of the transdisciplinary knowledge production model and associated actors and interactions involved. All fifteen students in the EEE 495 course, as well as twenty-five EPICS students, completed both the pre- and post-course intervention assessment surveys. Pre/post-course mean scores were calculated for all quantitative questions, and qualitative questions were thematically analyzed for considerations included in the design process with a 90% agreement in inter-rater reliability. (Items #11, 14, 16, 18, and 19 were excluded from analysis as they were ineffective measures, e.g., pre-assessment ratings were very high to begin with and/or did not change.) Coding for design considerations measures awareness of, understanding of, and ability to apply non-technical dimensions to community-based design. Whereas, analyzing the data for actors and interactions measures awareness of, understanding of, and ability to apply transdisciplinary knowledge production models in community-based design, as well as participant's awareness, understanding, and ability to apply non-technical dimensions to community-based design.

Reflections

Critical reflection can generate, deepen, and document learning, and can therefore serve as an effective tool to measure learning outcomes in service-learning and other educational settings.¹²¹

¹²² The two reflection exercises (Appendix C) used in this study were class assignments seeking to measure students' awareness of, understanding of, and ability to apply transdisciplinary knowledge production models in community-based design. All fifteen students in the EEE 495 course completed both reflections, which were conducted in the third and tenth weeks of the course. The raw data from the reflections was thematically analyzed for actors and interactions involved in the knowledge production process with 94% and 87% agreements in inter-rater reliability, respectively.

FINDINGS

EEE 495 Results

The subsequent sections present the results of the previously mentioned assessments (interviews, assessment survey, and reflections) and their contributions to increasing students' awareness of, understanding of, and ability to apply non-technical dimensions and a transdisciplinary knowledge production model in community-based design projects. All results are students' self-reported perceptions, and are organized by the following three constructs: *considerations*, *actors*, and *interactions*. The construct *considerations* was selected as it includes items and things to be thought about or considered during the design process, thus highlighting students' awareness of, understanding of, and ability to apply non-technical dimensions to design. The construct *actors* provides insight into students' awareness and understanding of individuals that are included and/or excluded in the transdisciplinary knowledge production model in community-based design projects. The construct *interactions* offers insights regarding students' awareness and

understanding of approaches, processes, and methods included and/or excluded in the transdisciplinary knowledge production model in community-based design projects. The majority of the results presented are from the EEE 495 intervention; however, a few samples of the EPICS skill session results are also highlighted at the end of the results section.

Considerations

Analysis of the qualitative and quantitative data from the interviews and assessment surveys showed increased student awareness of stakeholder considerations. In the interview data more specifically, stakeholder considerations accounted for 40% (32 of 80) of the coded responses in the pre-course interview versus 44% (35 of 80) in the post-course interview (Figure 4).

FIGURE 4
PRE/POST INTERVIEW FREQUENCY COUNTS OF CODED CONSIDERATIONS AND ASSOCIATED PERCENTAGES.

Even more notably, in the EEE 495 assessment survey data, stakeholder considerations increased from 13% (10 of 78) of the coded responses in the pre-course assessment survey to 31% (23 of 75) in the post-course assessment survey (Figure 5).

Assessment Survey (Question 2) Frequency Counts and Associated Percentages

FIGURE 5

PRE/POST ASSESSMENT SURVEY FREQUENCY COUNTS OF CODED CONSIDERATIONS AND ASSOCIATED PERCENTAGES.

Statistical analysis of the assessment survey data also provides evidence that there are significant differences between pre/post-course frequencies in mentions of stakeholder considerations (Table 4).

TABLE 4

NUMBER OF CODED RESPONSES FOR CONSIDERATIONS IN PRE/POST INTERVIEWS AND PRE/POST ASSESSMENT SURVEY QUESTION #2 AND ASSOCIATED STATISTICAL SIGNIFICANCE.

Consideration	Interviews, N = 5		Paired T-Test (p-value)	Assessment Survey (Q2) EEE 495, N = 15		Paired T-Test (p-value)	Assessment Survey (Q2) EPICS, N = 25		Paired T-Test (p-value)
	Pre	Post		Pre	Post		Pre	Post	
Technical Consideration	9	9	1.000	22	11	0.022*	14	5	0.047*
Stakeholder Consideration	32	35	0.753	10	23	0.003**	29	39	0.030*
Non-Technical Constraint	16	22	0.547	30	22	0.164	37	40	0.559
Broader Consideration	6	8	0.541	12	10	0.546	16	15	0.628
Total	63	74	0.180	74	66	0.041*	96	99	0.612

*significant at p-value < 0.05, **significant at p-value < 0.01

Additionally, the following excerpts from one subject highlight an example of the increase in stakeholder considerations in pre/post-course interview responses. Coded stakeholder considerations are underlined. In the pre-course interview response excerpt, stakeholder considerations are not mentioned, whereas in the post-course interview response excerpt they are mentioned three times.

Interview Question Prompt

In this course you have participated in a community-based design project. What types of knowledge or design concerns did you incorporate into your project?

Pre-Course Interview Response

“Budgetary constraints, all of the physical constraints, and then the time to get it done.”

Post-Course Interview Response

“The most important is satisfying the stakeholders’ needs and wants. Whatever the stakeholders identified as important for whatever reason, we valued it as important. If we deliver a project that ignores all of their requests and they don’t ever use it or it never gets actually completed then that defeats the purpose of the whole thing. Any concern or issue the stakeholders brought to the table was treated as important and addressed as such.”

Similar patterns emerge in the assessment survey results in the forced response, rank order questions, specifically in the first question regarding the kinds of information needed in designing a rain garden at a local science museum (#4). Of the thirteen forced responses included, four of them had a stronger stakeholder dimensionality (*handicapped accessibility, input from museum curator, neighborhood/user opinion, and safety*), hence they were more desirable in terms of transdisciplinary understanding. There were significant differences in the ranking of importance between pre/post-course frequencies in *input from museum curator* and *neighborhood/user opinion* in the EEE 495 data (< 0.01 and 0.004) (Table 5). As these items represent people directly-impacted by the design, and not just ideas related to people, i.e., *handicapped accessibility*, the significance in the selection of these items suggests a more nuanced understanding of differing levels of stakeholder consideration in the context in which the design is occurring.

TABLE 5
STUDENT PRE/POST-COURSE ASSESSMENT SURVEY RESULTS FOR A FORCED RESPONSE, RANK ORDER
QUESTION REGARDING THE KINDS OF INFORMATION NEEDED IN DESIGNING A RAIN GARDEN AT A
LOCAL SCIENCE MUSEUM.

Assessment Survey (Q4)

You have been asked to design a rain garden at a local science museum. You have a limited amount of time and resources to gather information that will be used throughout the duration of the design project. From the following list, RANK ORDER the kinds of information you would MOST LIKELY NEED as you work on your design.
(1 = most important, 13 = least important)

	Mean Rank EEE 495, N = 15		Paired T-Test (p-value)	Mean Rank EPICS, N = 25		Paired T-Test (p-value)
	Pre	Post		Pre	Post	
Handicapped Accessibility	9.8	10.4	0.279	9.0	8.8	0.504
Input from museum curator	7.1	3.8	< 0.01**	6.1	4.7	0.040*
Neighborhood/user opinions	6.6	3.3	0.004**	8.3	5.0	< 0.01**
Safety	5.4	6.8	0.865	4.0	3.5	0.418

*significant at p-value < 0.05, **significant at p-value < 0.01

In the second forced response, rank order question, regarding the relative importance of including each type of knowledge source, the choice of *stakeholders/users directly involved* as most important in relation to six other knowledge sources (i.e., general public, academics, non-academics, field engineers/scientists, policymakers/politicians, contractors) occurred more frequently in the post-course survey results. These results, however, were not at a significant level (see Appendix B for survey instrument).

Results from the construct *considerations* in the EPICS data set demonstrate similar patterns to the EEE 495 intervention regarding an increased awareness for and understanding of non-technical dimensions in community-based design projects. There are significant differences between pre/post-intervention frequencies of stakeholder considerations in assessment survey questions two and three (Table 4), as well as in assessment survey question four regarding *input from museum curator* and *neighborhood/user opinion* (Table 5). These findings suggest that simply having engaged discussions with students may be enough to at least heighten their awareness of stakeholder considerations, but perhaps may not be sufficient enough in increasing students' abilities to apply non-technical dimensions in community-based design projects.

Ultimately, the evidence presented across instruments for the construct *considerations* provides evidence of increased student awareness and understanding of stakeholder involvement in community-based design projects, i.e., non-technical dimensions. It also suggests that a transdisciplinary knowledge production model may enhance students' abilities to integrate non-technical dimensions in community-based design projects, thus increasing sustainability problem-solving competencies.

Actors

A coding rubric for the construct *actors* involved in transdisciplinary knowledge production for community-based design projects emerged from thematic analysis of the qualitative interview and reflection data. Using the rubric below (Figure 6), actors were sorted into two categories designating them as academics or non-academics. Academic and non-academic actors were then categorized based upon their association with the project at the focus of this study, i.e., directly- or indirectly-impacted.

FIGURE 6
CODING PROCEDURES AND A HIERARCHY FOR ACTORS INVOLVED IN TRANSDISCIPLINARY
KNOWLEDGE PRODUCTION.

When viewing the coded responses categorically, clear patterns emerge. Due to the intervention, as expected, the raw number of total coded actors increased from the first to second sets of interview and reflection data. Specifically, in the non-academic and directly-impacted categories, increases were statistically significant demonstrating greater depth and sophistication in understanding of the design context and relationship among the actors involved (Table 6).

TABLE 6

NUMBER OF CODED RESPONSES FOR ACTORS INVOLVED IN TRANSDISCIPLINARY KNOWLEDGE PRODUCTION IN COMMUNITY-BASED DESIGN PROJECTS IN INTERVIEW AND REFLECTION DATA FROM EEE 495 STUDENTS WITH ASSOCIATED STATISTICAL SIGNIFICANCE

Actors	Interviews, N = 5		Paired T-Test (p-value)	Reflection, N = 15		Paired T-Test (p-value)
	Pre	Post		Pre	Post	
Academics	25	26	0.944	98	163	0.002**
Non-Academics	65	120	0.032*	164	249	0.096
Directly-Impacted	59	122	0.039*	166	352	0.002**
Indirectly-Impacted	26	19	0.515	65	50	0.408
Totals	175	287	0.112	493	814	0.010*

*significant at p-value < 0.05, **significant at p-value < 0.01

The excerpts below from one participant highlight the increased depth and sophistication of responses between the two sets of reflection data. Coded non-academic, directly-impacted actors are underlined. This example highlights significantly more mentions of non-academics in the second reflection.

First Reflection Response

"The necessary actors involved in the development of transdisciplinary knowledge will vary from project to project. In general, each project may be broken down into multiple facets. There should be a team member that specializes in each of the facets. For instance, a project may require a technical specialist, a policy specialist, a non-technical scientific specialist, a design specialist, etc."

Second Reflection Response

"We are all very different, yet have similar goals and needs/desires for the project. We are the River University student team, but we are also working with the Johnson students, Urban Landscapers (contractors), Tree City, River Stewards, The Water Foundation, The Johnson School Corporation, and The City of Johnsonville. Each group has something important to contribute including design work, installation labor, professional expertise, funding, publicity, and use of the project. The project would not be the same, and may not be successful, without collaboration between all parties, and an integration of each area of expertise. Aside from the variety of major stakeholders included, there is also great variety in the background of the River University student team. We come from different majors including environmental engineering, natural resources and environmental science, political science, and landscape architecture and design. This variety has given us the tools necessary to comprehensively assess the problem and find a solution. It has been an incredible learning experience, but has not been an easy road."

Across both instruments, the data provides evidence that there are significant differences over time in frequencies of students referring to directly-impacted actors. A slight increase in understanding of actors involved in transdisciplinary knowledge production also occurred in the assessment survey results in the Likert scale questions although these results were not statistically significant (#13, 15, and 17) (Table 7).

TABLE 7
STUDENT PRE/POST ASSESSMENT SURVEY RESULTS FOR QUESTIONS 13, 15, AND 17 REGARDING
UNDERSTANDING OF ACTORS INVOLVED IN TRANSDISCIPLINARY KNOWLEDGE PRODUCTION IN
COMMUNITY-BASED DESIGN PROJECTS.

Assessment Survey (Q13, 15 & 17)

For questions 13-19, please circle the number that best represents your perceptions.
(1 = strongly disagree, 5 = strongly agree)

	Mean Rank EEE 495, N = 15	
	Pre	Post
It is important to incorporate information from multiple participants (scientists, academics, stakeholders, general public) in the community-based design process	4.9	5
Considering local context (i.e., current uses of the project site, opinions of those affected by the projects, etc.) during the design process is important.	4.7	5
Academics and non-academics should collaborate to create transdisciplinary knowledge for community-based designed projects.	4.6	5

The evidence presented across instruments for the construct *actors* provides support for an increased awareness and understanding of the need to include directly-impacted, non-academic actors in community-based design projects. It also suggests that a transdisciplinary knowledge production model may enhance students' abilities to integrate non-technical dimensions in community-based design projects, thus increasing sustainability problem-solving competencies.

Interactions

A coding rubric for the construct *interactions* involved in transdisciplinary knowledge production for community-based design projects also emerged from thematic analysis of the qualitative interview and reflection data. Segments of text discussing strings of connected interactions were identified, and then specific interactions were extracted from the excerpt and coded into five emerging categories: collaborating, defining the problem, integrating, mutual learning, and emerging knowledge (see Figure 7 for definitions of each interaction).

FIGURE 7
CODING HIERARCHY FOR INTERACTIONS INVOLVED IN TRANSDISCIPLINARY KNOWLEDGE PRODUCTION.

Co-occurring interactions within the segments of text also emerged. Table 8 displays the top five patterns of interactions for the interview and second reflection data sets. The excerpts below from one participant highlight an example of interactions mentioned in the reflection data. Coded interactions and associated patterns are designated by underlining.

Reflection Response Representing the Pattern: “Collaborating” (C)

“For this type of knowledge to emerge, a variety of players can be involved in the discussion about a particular project, practice, or concept.”

Reflection Response Representing the Pattern: “Collaborating, defining the problem, integrating, mutual learning, and emerging knowledge” (CDIME)

“It is, therefore, important to collaborate on all aspects of the design and idea creating process. When a problem needs to be defined, both the academics and the non-academics need to collaborate, understand each other’s perspectives, and come to a consensus on the definition of the problem. Both groups will see the problem with a different perspective as well as the solution. As both perspectives come together, a higher knowledge is achieved as well as a more effective outcome. The outcome produced and

the knowledge gained with will be more useful and effective because the perspective on all of the processes has been broadened."

TABLE 8
NUMBER OF CODED RESPONSES FOR TOP FIVE INTERACTION PATTERNS INVOLVED IN
TRANSDISCIPLINARY KNOWLEDGE PRODUCTION IN COMMUNITY-BASED DESIGN PROJECTS IN
PRE/POST INTERVIEW AND REFLECTION DATA FROM EEE 495 STUDENTS WITH ASSOCIATED
STATISTICAL SIGNIFICANCE.

Interaction Patterns	Interviews, N = 5		Paired T-Test (p-value)	Reflection, N = 15		Paired T-Test (p-value)
	Pre	Post		First	Second	
Collaborating (C)	4	3	0.749	5	20	0.002**
Integrating (I) ^a	4	0	0.016*	--	--	--
Collaborating and Integrating (CI) ^a	1	4	0.208	--	--	--
Collaborating & Mutual Learning (CM) ^b	--	--	--	13	4	0.308
Collaborating, Integrating, & Emerging Knowledge (CIE) ^b	--	--	--	3	7	0.164
Collaborating, Integrating, & Mutual Learning (CIM)	2	5	0.374	8	6	0.433
Collaborating, Integrating, Mutual Learning, & Emerging Knowledge (CIME)	3	4	0.704	11	12	0.827
Totals	14	16	0.778	40	49	0.672

*significant at p-value < 0.05, **significant at p-value < 0.01

^a Top five most common patterns for interviews data only

^b Top five most common patterns for reflection data only

(--) indicate no mentions of this pattern

Fourteen total patterns emerged from analysis of the interview data, whereas nineteen emerged from the reflection data. In both data sets, *collaborating*, either as a singular interaction or paired with another interaction, occurred the most frequently among the patterns (9 of 14 times in the interview data and 12 of 19 in the reflection data) followed closely by *integrating* (9 of 14 times and 10 of 19 times) and *mutual learning* (9 of 14 times and 10 of 19 times). *Emerging knowledge*, either as a singular interaction or paired with another interaction occurred 5 of 14 times and 8 of 19 times, whereas *defining the problem* occurred least frequently across both data sets (3 of 14 times and 5 of 19 times). The pattern for the cumulative set of interactions required for the transdisciplinary knowledge production model, *collaborating*, *defining the problem*, *integrating*, *mutual learning*, and *emerging knowledge* (CDIME) only occurred in the interview data set (4 instances in the pre-course and 4 instances in the post-course data). The data provides evidence

that there are significant differences between mentions of *collaborating* in the first and second sets of reflection data, and in mentions of *integrating* in the pre/post-course interview data. Additionally, a slight increase in understanding of interactions involved in transdisciplinary knowledge production occurs in the assessment survey results in Likert scale questions #8, 9, and 10 (Table 9).

TABLE 9
STUDENT PRE/POST ASSESSMENT SURVEY RESULTS FOR QUESTIONS 8, 9, AND 10 REGARDING
UNDERSTANDING OF INTERACTIONS INVOLVED IN TRANSDISCIPLINARY KNOWLEDGE PRODUCTION
IN COMMUNITY-BASED DESIGN PROJECTS.

Assessment Survey (Q8, 9 & 10)

For questions 8-11, indicate your agreement with each statement below.
(1 = strongly disagree, 5 = strongly agree)

	Mean Rank EEE 495, N = 15	
	Pre	Post
Creating transdisciplinary knowledge involves working together	4.9	4.9
Creating transdisciplinary knowledge involves combining knowledge	4.7	4.9
Creating transdisciplinary knowledge involves learning from others	3.8	3.8

The evidence presented across instruments for the construct *interactions* provides support for an increased awareness and understanding of the need to *collaborate* with stakeholders and *integrate* multiple knowledge sources and information in community-based design projects. The presence of *mutual learning* in multiple instances across the top five occurring patterns suggests an increased awareness and understanding of the value in learning from others, specifically stakeholders involved in the project. These results suggest that a transdisciplinary knowledge production model may enhance students' abilities to not only integrate non-technical dimensions, but also engage with stakeholders in community-based design projects, thus increasing sustainability problem-solving competencies.

Converging Results Across Constructs

Results across all three constructs, *considerations*, *actors*, and *interactions*, clearly demonstrate an increased awareness of, understanding of, and ability to apply non-technical dimensions to community-based design projects. In assessment survey Likert scale questions #5, 6, and 7, students also reported that the educational intervention significantly increased their understanding of transdisciplinary knowledge production (Figure 8).

Understanding of Transdisciplinary Knowledge Production

FIGURE 8

STUDENT PRE/POST-COURSE ASSESSMENT SURVEY RESULTS FOR QUESTIONS 5, 6, AND 7 REGARDING UNDERSTANDING OF TRANSDISCIPLINARY KNOWLEDGE PRODUCTION IN COMMUNITY-BASED DESIGN PROJECTS.

Holistically, these results also suggest the potential for a transdisciplinary knowledge production model to provide a platform for increasing sustainability problem-solving competencies in engineering, i.e., an understanding of the broader impact of design solutions and non-technical dimensions in design. While the previously mentioned results reveal strong support for the effectiveness of the intervention, the following two student excerpts from the second reflection data seek to qualitatively illustrate the connectivity between the transdisciplinary knowledge production-focused intervention and an increase in students' engineering competencies in sustainability problem solving.

Excerpt One

“Teaching the principles of transdisciplinary knowledge to a student design team will both broaden each team member’s perspective and improve the effectiveness of the team’s project. Today’s university student is given an in-depth education on their particular subject or field of study, and therefore regularly have biases regarding how to view and solve a problem; transdisciplinary knowledge opens new perspectives to these students and allows them to view both problems and solutions in a new light. Additionally, community-based projects are more effective when using a transdisciplinary approach. Since multiple players are collaborating, the final solution will serve everyone’s needs as fully as possible. When the design team leaves the project at the end of the semester, they will see their work reflected in the project—but they will have also given the other players a stake in the project, and therefore the project is more likely to be maintained in the long term.”

Excerpt Two

“This class is unique because it gives us, the students, an opportunity to interact and learn from people outside our university. This includes stakeholders, community members, and our project partner. For our project we have been in contact with many people outside of River University in order to ensure our success and create a design that is needed and welcomed by the community. So far we have met with and gained insight from the students at Johnson Middle School, faculty at Johnson Middle School and representatives from Urban Landscapers and River Stewards. Information gained from these interactions allows us to create a design with a high impact. Getting their input is imperative to our success and gives us a holistic view of the project and how it affects people in the community. Overall, the idea of transdisciplinary knowledge applies the concept of synergy and that collaboration with others outside of our academic discipline and academics in general will give us a result greater and more effective than anything we could have produced alone.”

In the first excerpt, phrases like “broaden each team member’s perspective” and “opens new perspectives to these students and allows them to view both problems and solutions in a new light” indicate an increased awareness and understanding of non-technical dimensions to be included in community-based design projects, as well as the importance to including multiple stakeholders. This is also reflected in the second excerpt in statements such as “learn from people outside of our university. This includes stakeholders, community members, and our project partner and getting their input is imperative to our success and gives us a holistic view of the project.” Phrases like “multiple players are collaborating” and “when the design team leaves the project...their work reflected in the project—but they will have also given the other players a stake” in the first excerpt, and “opportunity to interact and learn from people outside our university and collaboration with others outside of our academic discipline and academics in general will give us a result greater” in the second excerpt highlight the need for transdisciplinary knowledge production approaches. For additional interview and reflection data and further insights on this study see Payne.¹²³

DISCUSSION

Results of this transdisciplinary knowledge production model-focused intervention in a PBL, service-learning environment provided evidence of an increase in students' awareness of, understanding of, and ability to apply non-technical dimensions in a community-based design project. Specifically, students demonstrated increased awareness and understanding of: stakeholder considerations, the need to collaborate with stakeholders, the need to integrate knowledge from multiple sources, and the importance of learning from stakeholders. This study further advances our understanding of appropriate learning environments, teaching methods, and assessment tools for developing engineering competencies in sustainability problem solving. While results from this study were not generalizable due to the small sample size, they are potentially transferable to similar classroom learning environments. There are, however, some important points of discussion to be addressed if this study is to be replicated in another setting. The following sections provide recommendations for future work and usage of the learning environment strategies, transdisciplinary knowledge production model, and assessment tools.

The Stakeholder Story and Transdisciplinary Interactions

The interventions described in this paper offered support for the learning of non-technical dimensions, specifically the “stakeholder story,” i.e., an increase in students' awareness and understanding of stakeholder considerations, the need to collaborate with stakeholders, the need to integrate multiple sources of knowledge, and the importance of learning from stakeholders in engineering design as called for by various scholars and accreditation entities.^{124 125 126 127} This evidence points to clear linkages between the use of a PBL, service-learning environment and an increase in stakeholder engagement in community-based design projects concurring with the work of Al-Khafaji and Morse¹²⁸ and Clevenger and Ozbek,¹²⁹ as well as the broader body of literature on service-learning. Given the weekly contact students had with their community partners in the first intervention, this was an expected outcome. Less pronounced changes were also evident in the EPICS skill session data, suggesting that prolonged, consistent contact with partners is a critical component to enhancing this type of learning.

To a lesser degree, students' understanding of the suite of processes involved in the transdisciplinary knowledge production model was gained from this intervention. Thus, additional learning activities are likely needed to increase students' understanding of all of the interactions involved in the process and how those interactions help facilitate the inclusion of non-technical dimensions. Students clearly understood the need to *collaborate*, specifically with stakeholders, but were unable to consistently articulate other interactions, specifically the combination of interactions needed to produce transdisciplinary knowledge (i.e., CDIME—*collaborating, defining the problem, integrating, mutual learning, and emerging knowledge*—occurring only in the interview dataset). Hence, developing and deploying more structured, formalized activities to support learning in this regards would be beneficial.

Enhancing the stakeholder story and an understanding of the processes needed for transdisciplinary knowledge production could be supported by increased opportunities for critical reflection to generate, document, and deepen learning in experiential learning settings.^{130 131 132 133} In the engineering classroom specifically, Chen et al.¹³⁴ have shown that the use of social media applications, i.e., weblogs, wikis, portfolios can increase reflective learning and positively

influence students' knowledge, awareness, and skills in engineering design. Additionally, Schön¹³⁵ suggests that *reflection in action* is a defining characteristic of professional practice and is critical for future practitioners in a variety of fields. In the classroom, large-group reflective discussions can be held intermittently throughout the semester to apply Schön's concept of *reflection in action*.

In the more specific context of understanding the broader impact of design solutions, i.e., non-technical dimensions of design, it would be useful to have students explicitly identify different types of considerations included or excluded in the design process in small reflection assignments. In the reflection assignments used in the course described in this study, students were asked to reflect upon the transdisciplinary knowledge production process, but without necessarily explicitly highlighting design considerations. In these new, proposed assignments, students would describe not only how these considerations were included or excluded in their design, but also how awareness of such considerations impacted their problem-solving processes. Larger in-class group reflection opportunities categorizing considerations occurring in the design process might also help students reflect upon both their own and the class' growth in understanding of non-technical dimensions in community-based design, and perhaps also encourage growth in awareness and understanding of other considerations outside of stakeholder considerations (i.e., non-technical constraints and broader considerations, see Figure 3). In regards to the transdisciplinary knowledge production processes, additional in-class group reflection would also be beneficial. If staggered throughout the semester, this would provide students with opportunities to share the processes in which they had been engaging project stakeholders in real time, as well as offer an opportunity to link these real world experiences back to the theoretical model in a formalized, reinforcing learning environment.

A final point to address in the transdisciplinary knowledge production model is the low instances of mention of the interaction labeled *defining the problem*. As Downey¹³⁶ has argued, this may be due to the fact that engineers are good at defining and solving technical problems, but are not as proficient at defining and solving problems on the "periphery." As this project involved an ill-defined problem coupled intimately with stakeholder needs, students struggled with bounding the issue and recognizing their role in the problem definition space. It may therefore be useful to reframe introductory lessons and activities to use problem scoping exercises and focus upon problem definition versus a traditional orientation toward problem solving.¹³⁷ Another approach would be to create opportunities for students to participate in facilitating the partnership prior to taking a related course, which inherently includes defining, situating, and clarifying the problem among partners in the broader context. In this sense, students would help identify issues and develop relationships among partners from the outset.

Fostering Sustainability Problem-Solving Competencies

The use of a transdisciplinary knowledge production model additionally enriched the PBL and service-learning intervention by fostering the development of engineering competencies in sustainability problem solving, specifically in the area of offering frameworks for meaningful collaboration and knowledge integration among academics, practitioners, and stakeholders.^{138 139}

^{140 141} Throughout the semester, students participated in off-site design charrettes with their community partners and collaboratively developed and refined their designs through multiple iterative feedback sessions via face-to-face contact, phone calls, and/or emails. They also collaborated with academics in stormwater management, hydrology, and native ecosystems. To

complement the academic perspective, practitioners were brought into the classroom to talk about city stormwater management and local conservation efforts surrounding the river. Lastly, students worked closely with a green landscaping company to integrate their real-world, professional expertise into the project. This multi-pronged approach provided a foundation for applying the transdisciplinary knowledge production model in context, as sending students off campus to meet with their partner and bringing outside individuals into the classroom inherently placed value upon their expertise, as well as exposed students directly to multiple knowledge channels relevant to the project. This would not have occurred had a traditional pedagogical approach and model for knowledge production (i.e., multidisciplinary or interdisciplinary, see Figure 1) been employed. Nonetheless, it should be noted that implementing a course and model such as this can be resource-intensive, require higher level of flexibility in curriculum and assessments, introduce scheduling challenges due to differing timelines between the university and community partner, and ultimately require a willingness to give project control to students engaging in the experience.¹⁴²

Assessment Tools

A third area of discussion revolves around the assessment tools emerging from this work. All effective educational practice involves systematic assessment of learning, and in this specific case, two emergent assessment instruments from the data analysis proved to be highly effective at this task: the *actors* coding rubric and the *interactions* coding rubric. While these instruments are context-specific, both could be modified for use in other learning environments, and thus be useful for those embarking upon similar curricular interventions and investigations, specifically providing support for the much needed documentation and assessment of transdisciplinary-focused curricular interventions as called for by Remington-Doucette et al.¹⁴³ The *actors* coding rubric for individuals included and/or excluded in the transdisciplinary knowledge production model identified the frequency and type of actors with a very high inter-rater reliability, i.e., 94% in both the interview and reflection data analysis (see Figure 6). By modifying the definitions and providing relevant examples for each category within the rubric, this tool could be used in other design-based courses in engineering and other fields, such as technology, construction, landscape architecture, natural resources management, and urban planning, to assess the transdisciplinary knowledge production-focused curricular intervention.

The same could be done for the *interactions* rubric that codes for processes and methods included and/or excluded in the transdisciplinary knowledge production model. This rubric identified the frequency and type of the required interactions for the model (i.e., *collaborating*, *defining the problem*, *integrating*, *mutual learning*, and *emerging knowledge*, see Figure 7), again, with very high levels of inter-rater reliability, i.e., 87% in both the interview and reflection data analysis. This instrument also facilitated the identification of patterns in associated interactions. Both tools provided effective assessment measures for corroborating learning and/or identifying gaps in the learning of *actors* and *interactions* involved in the transdisciplinary knowledge production model.

It should also be noted that while these two assessment tools proved to be useful in this study, value would be added to a future study if additional instruments measuring students' abilities to apply non-technical dimensions in design were included. For instance, observational data could be collected during group presentations and stakeholder feedback sessions identifying *considerations*, *actors*, and *interactions*, as well as noting the inclusion or exclusion of these components into the

design solution. It would also be useful to examine class artifacts, such as project proposals and design drafts, for the presence of non-technical dimensions, as well as actors and interactions associated with the transdisciplinary knowledge production model. Additionally, if time allowed, a larger sample of student interviewees would add richness to the study results.

Self-Selection Story

Lastly, it should be noted that there is a strong self-selection story likely influencing the results of this study given that students participating in the EEE 495 course from the outset exhibited greater tendencies toward involving stakeholders in community-based design projects, as evident in their high pre-course assessment scores. For instance, in Likert scale questions #8, 9, 13, 15, and 17 all means were above 4.5 in the pre-course assessment (4.9, 4.7, 4.9, 4.7, and 4.6, respectively) (Tables 7 and 9). Yet despite these high initial competency scores, evidence from this study suggests notable increases in competencies among even these high-performing students.

Additionally, three students from majors outside of engineering (e.g., political science, natural resources and environmental science, and landscape architecture) elected to take the course. As a result, there was potential for their different disciplinary perspectives to influence the engineering students' understanding of necessary design consideration. The interview and reflection data, however, demonstrated a surprising lack of explicit references to other disciplines when students were asked to identify design considerations. In fact, evidence of such awareness only occurred once, namely in the second set of reflection responses. This is likely a result of the transdisciplinary knowledge production model influencing students to subconsciously group themselves with all academic actors rather than separate their disciplinary perspectives (see Figure 2). Furthermore, efforts to focus on integrating knowledge outside of academia and enhance collaboration opportunities with community partners, through the transdisciplinary knowledge production model and service-learning pedagogical strategy, may have predisposed students to focus more intently upon external actors and knowledge versus different sources of disciplinary expertise internal to the academic context. Such dynamics would be worth further exploration and investigation in future educational interventions and/or research efforts.

CONCLUSION

This research addressed the need for engineering students to be more effective at integrating the non-technical dimensions of sustainability into their design solutions. It specifically assessed how a transdisciplinary knowledge production model-focused case study in an environmental and ecological engineering PBL, service-learning, community-based design course affected students' awareness of, understanding of, and ability to apply non-technical dimensions into design solutions, as well as increase their engineering competencies in sustainability problem solving. Three assessment techniques were used in a pre/post assessment approach: interviews, surveys, and reflections. Data were analyzed based upon the following constructs: considerations in design, as well as actors and interactions in transdisciplinary knowledge production.

From this work, the following three critical outcomes emerged. First, the results demonstrated that this specific intervention in community-based design increased students' awareness and understanding of: stakeholder considerations; the need to collaborate with stakeholders and integrate multiple knowledges and types; and the importance of learning from stakeholders.

Second, the results suggest that a transdisciplinary knowledge production model may enhance the ability of students to not only integrate non-technical dimensions, but also engage with stakeholders in community-based design projects. Lastly, for educational practitioners, this research provided a roadmap for integrating these concepts into course pedagogical strategies, curricula, and assessments, specifically aligned with increasing students' learning surrounding non-technical dimensions in community-based design, as well as increasing their sustainability competencies.

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APPENDICES

Appendix A: Pre- & Post-interviews

Pre-Interview Guide

Script

Thank you for agreeing to participate in this study. As you know, this study is designed to evaluate the effectiveness of a curricular intervention on increasing engineering students' awareness, understanding, and ability to apply transdisciplinary knowledge in community-based design projects. As a participant in this pre-interview, at the end of the semester you will also be asked to participate in a post-interview which will take about 30 minutes. As a reminder, all of your responses will remain confidential and will not be reviewed until after grades are submitted. Lastly, if you complete all of the study procedures, you will receive 1% extra credit toward your overall course grade. This interview will be audio recorded. During the interview you may choose to not answer a question. Additionally, if you do not know the answer, please say so and we will move to the next question. Any questions?

Interviewee identifier

1. Please provide the last 4 digits of your cell phone #: _____

Individual skills

2. What are your strongest design skills? Can you give any examples of specific projects or assignments where you used these skills?
3. What are your weakest design skills? Can you give any examples of specific projects or assignments where you became aware of these weaknesses?

Design concerns

4. In this course you will be participating in a community-based design project. What types of knowledge or design concerns might you want to incorporate into your project?
 - a. Follow-up probes for students who do not mention these types of considerations: What people or groups would be most important to involve? What knowledge or information might be most important to consider? What criteria do you think are most important to consider? What process(es) would you use for design? (Etc.)
5. What types of knowledge and/or design concerns do you think are least important or even irrelevant when doing a community-based design project?

Transdisciplinary knowledge

6. This course is titled: Transdisciplinary knowledge through innovative campus-community partnerships. How would you define transdisciplinary knowledge?
7. What processes might be involved in producing transdisciplinary knowledge?
8. What individuals might be involved in producing transdisciplinary knowledge?
9. How might you apply transdisciplinary knowledge to a community-based design project?
10. As a future professional, what barriers might prevent you from producing transdisciplinary knowledge?

11. As a future professional, what might be some benefits associated with using a transdisciplinary approach to community-based design projects?

Post-Interview Guide

Script

Thank you again for agreeing to participate in this study. As you know, this study is designed to evaluate the effectiveness of a curricular intervention on increasing engineering students' awareness, understanding, and ability to apply transdisciplinary knowledge in community-based design projects. As a reminder, all of your responses will remain confidential and will not be reviewed until after grades are submitted. This interview will be audio recorded. During the interview you may choose to not answer a question. Additionally, if you do not know the answer, please say so and we will move to the next question. Any questions?

Interviewee identifier

1. Please provide the last 4 digits of your cell phone #: _____

Individual skills

2. What are your strongest design skills? Can you give any examples of where you used these skills in the class projects?
3. What are your weakest design skills? Were these skills improved during the class, if so, how?
4. What are your career goals? i.e., in what type of job/organization do you see yourself working in the next 3-5 years?

Design concerns

5. In this course you have participated in a community-based design project. What types of knowledge or design concerns did you incorporate into your project?
 - a. Follow-up probes for students who do not mention these types of considerations: What people or groups would be most important to involve? What knowledge or information might be most important to consider? What criteria do you think are most important to consider? What process(es) would you use for design? (Etc.)
6. What types of knowledge and/or design concerns do you think are least important or even irrelevant when doing a community-based design project?

Transdisciplinary knowledge

7. This course is titled: Transdisciplinary knowledge through innovative campus-community partnerships. How would you define transdisciplinary knowledge?
8. What processes might be involved in producing transdisciplinary knowledge?
9. What individuals might be involved in producing transdisciplinary knowledge?
10. Provide examples of how you applied a transdisciplinary approach to your design project?
11. How useful was the transdisciplinary approach in designing your project? Please explain.
12. In your project you used a transdisciplinary approach in a design project with a local school, how might you use this type of approach in the future?
 - a. Follow up probe: in your future profession?

13. What barriers might prevent you from using a transdisciplinary approach in the future?
How might you overcome these barriers?
 - a. Follow up probes: in your future profession? How might you overcome these barriers?
14. What might be some benefits associated with using a transdisciplinary approach in the future?
 - a. Follow up probe: in your future profession?
15. Lastly, in your class project it was apparent that communication was a key part of the transdisciplinary approach. Where would you place “communication” on the transdisciplinary approach framework?
 - a. Note: mark student’s suggestion on the framework

Appendix B: Pre- & Post-assessment survey

Pre-assessment survey

This study is designed to evaluate the effectiveness of a curricular intervention on increasing engineering students' awareness, understanding, and ability to apply transdisciplinary knowledge in community-based design projects. For completing all study procedures, participating students will receive 1% extra credit toward their overall course grade. Students who do NOT complete all study procedures will NOT receive any compensation (extra credit). However, your participation in this study is strictly voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled. If you have questions, comments or concerns about this research project, please contact Dr. Brent Jesiek, 765-496-1531, bjesiek@purdue.edu.

Thank you in advance for your participation!

1. For tracking purposes, please list the **last 4 digits** of your cell phone number. _____
(Example: If the number is 949-357-4514, the response would be 4514.)

Part 1 of 3: Scenario Questions

Please answer questions 2 and 3 based on Scenario A.

Scenario A: In the small town of Waterville, storm water runoff into the local river is a critical problem leading to polluted waterways. Large-scale water management systems are currently in place to remediate the issue, but small-scale community-based projects are needed to further improve conditions and increase public awareness. Imagine that you and your team are assigned to design a small-scale water project in partnership with a local school and non-profit. The school experiences standing water after a rain event and all downspouts are directly connected to the storm water system which ultimately ends up in the local river untreated. The local non-profit specializing in community-based urban water projects has suggested installing a constructed wetland on the school grounds to alleviate these issues.

2. In your opinion, what are the **five** most important things that you need to consider in order to successfully accomplish this design task? Please list them below (a-e).

RANK (1-5)

a.	_____	_____
b.	_____	_____
c.	_____	_____
d.	_____	_____
e.	_____	_____

3. After you have written all five considerations, use the right-hand "RANK" column to RANK ORDER the relative importance of each consideration, from 1=most important down to 5=least important.

Please answer question 4 based on Scenario B.

Scenario B: You have been asked to design a rain garden at a local science museum. You have a limited amount of time and resources to gather information that will be used throughout the duration of the design project.

4. From the following list, RANK ORDER the kinds of information you would MOST LIKELY NEED as you work on your design. (1 = most important, 13 = least important)

- _____ Availability of materials
- _____ Budget
- _____ Handicapped accessibility
- _____ Information about the site environment
- _____ Input from the museum curator
- _____ Labor and material cost
- _____ Legal liability
- _____ Neighborhood/user opinions
- _____ Safety
- _____ Supervision/maintenance concerns
- _____ Technical references/standards
- _____ Zoning/building codes and regulations
- _____ Other

Part 2 of 3: Survey Questions

***For questions 5-7, please circle the number that best represents your perceptions.
(1 = Strongly Disagree, 5 = Strongly Agree)***

5.	I know how to apply a transdisciplinary approach to community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree
6.	I can describe the processes needed to generate transdisciplinary knowledge for community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree
7.	I can describe the type of individuals needed to generate transdisciplinary knowledge for community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree

For questions 8-11, please mark an 'x' indicating your agreement with each statement below.
Creating transdisciplinary knowledge involves...

8. Working **together** _____ Working **alone**
9. **Segmenting** knowledge _____ **Combining** knowledge
10. Solving problems **for** others _____ Learning **from** others
11. Non-Academics _____ Academics

12. When designing a local urban water project, RANK ORDER the relative importance of including each knowledge source. (1 = most important, 7 = least important)

- _____ Stakeholders/users directly involved
_____ General public
_____ Academics
_____ Non-academics
_____ Field engineers/scientists
_____ Policymakers/politicians
_____ Contractors

For questions 13-19, please circle the number that best represents your perceptions.
(1 = Strongly Disagree, 5 = Strongly Agree)

13.	It is important to incorporate information from multiple participants (scientists, academics, stakeholders, general public) in the community-based design process.	Strongly Disagree	1 5	2	3	4	Strongly Agree
14.	Identifying environmental, social, political, and economic issues surrounding local urban water projects is <u>not</u> important in the design process.	Strongly Disagree	1 5	2	3	4	Strongly Agree
15.	Considering local context (i.e., current uses of the project site, opinions of those affected by the projects, etc.) during the design process is important.	Strongly Disagree	1 5	2	3	4	Strongly Agree
16.	Transdisciplinary knowledge is typically generated by experts working alone.	Strongly Disagree	1 5	2	3	4	Strongly Agree
17.	Academics and non-academics should collaborate to create transdisciplinary knowledge for community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree
18.	Learning from others is <u>not</u> important when creating transdisciplinary knowledge.	Strongly Disagree	1 5	2	3	4	Strongly Agree

19.	When creating transdisciplinary knowledge, information from academics and non-academics should be valued equally.	Strongly Disagree	1 5	2	3	4	Strongly Agree
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Part 3 of 3: Demographic Questions

20. What is your major? _____

21. What is your minor? _____

22. What is your current academic status?

- ☐ First-year
☐ Sophomore
☐ Junior
☐ Senior
☐ Other: _____

23. What is your gender?

- ☐ Male ☐ Female ☐ I prefer not to respond

24. What is your current age? _____

25. How do you describe your race and ethnicity?

- ☐ African American or Black
☐ American Indian/Alaska Native
☐ East Asian
☐ South Asian
☐ Hispanic
☐ Native Hawaiian or other Pacific Islander
☐ White
☐ Other/Mixed: _____
☐ I prefer not to respond

26. Please indicate your primary country of citizenship:

27. I have participated in a design project with community partners and stakeholders, e.g., EPICS, Global Design Team, Engineers Without Borders, etc.

- ☐ Yes ☐ No ☐ Unsure

28. If your answer to the previous question was “Yes”, approximately how many total semesters have you actively participated in such projects and where did they occur (city, state/region, and/or country)?

29. Would you be willing to participate in a short follow-up interview (30 minutes or less)?
_____ Yes _____ No

Thank you for your responses!

Post-assessment survey

This study is designed to evaluate the effectiveness of a curricular intervention on increasing engineering students' awareness, understanding, and ability to apply transdisciplinary knowledge in community-based design projects. For completing all study procedures, participating students will receive 1% extra credit toward their overall course grade. Students who do NOT complete all study procedures will NOT receive any compensation (extra credit). However, your participation in this study is strictly voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled. If you have questions, comments or concerns about this research project, please contact Dr. Brent Jesiek, 765-496-1531, bjesiek@purdue.edu.

Thank you in advance for your participation!

1. For tracking purposes, please list the **last 4 digits** of your cell phone number.

(Example: If the number is 949-357-4514, the response would be 4514.)

Part 1 of 2: Scenario Questions

Please answer questions 2 and 3 based on Scenario A.

Scenario A: In the small town of Waterville, storm water runoff into the local river is a critical problem leading to polluted waterways. Large-scale water management systems are currently in place to remediate the issue, but small-scale community-based projects are needed to further improve conditions and increase public awareness. Imagine that you and your team are assigned to design a small-scale water project in partnership with a local school and non-profit. The school experiences standing water after a rain event and all downspouts are directly connected to the storm water system which ultimately ends up in the local river untreated. The local non-profit specializing in community-based urban water projects has suggested installing a constructed wetland on the school grounds to alleviate these issues.

2. In your opinion, what are the **five** most important things that you need to consider in order to successfully accomplish this design task? Please list them below (a-e).

	RANK (1-5)
a. _____	_____
b. _____	_____
c. _____	_____
d. _____	_____
e. _____	_____

3. After you have written all five considerations, use the right-hand "RANK" column to RANK ORDER the relative importance of each consideration, from 1=most important down to 5=least important.

Please answer question 4 based on Scenario B.

Scenario B: You have been asked to design a rain garden at a local science museum. You have a limited amount of time and resources to gather information that will be used throughout the duration of the design project.

4. From the following list, RANK ORDER the kinds of information you would MOST LIKELY NEED as you work on your design. (1 = most important, 13 = least important)

- _____ Availability of materials
- _____ Budget
- _____ Handicapped accessibility
- _____ Information about the site environment
- _____ Input from the museum curator
- _____ Labor and material cost
- _____ Legal liability
- _____ Neighborhood/user opinions
- _____ Safety
- _____ Supervision/maintenance concerns
- _____ Technical references/standards
- _____ Zoning/building codes and regulations
- _____ Other: _____

Part 2 of 2: Survey Questions

For questions 5-7, please circle the number that best represents your perceptions. (1 = Strongly Disagree, 5 = Strongly Agree)

5.	I know how to apply a transdisciplinary approach to community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree
6.	I can describe the processes needed to generate transdisciplinary knowledge for community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree
7.	I can describe the type of individuals needed to generate transdisciplinary knowledge for community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree

For questions 8-11, please mark an 'x' indicating your agreement with each statement below. Creating transdisciplinary knowledge involves...

8. Working together _____ Working alone
9. Segmenting knowledge _____ Combining knowledge
10. Solving problems for others _____ Learning from others

11. Non-Academics _____ Academics

12. When designing a local urban water project, RANK ORDER the relative importance of including each knowledge source. (1 = most important, 7 = least important)

- _____ Stakeholders/users directly involved
- _____ General public
- _____ Academics
- _____ Non-academics
- _____ Field engineers/scientists
- _____ Policymakers/politicians
- _____ Contractors

*For questions 13-19, please circle the number that best represents your perceptions.
(1 = Strongly Disagree, 5 = Strongly Agree)*

13.	It is important to incorporate information from multiple participants (scientists, academics, stakeholders, general public) in the community-based design process.	Strongly Disagree	1 5	2	3	4	Strongly Agree
14.	Identifying environmental, social, political, and economic issues surrounding local urban water projects is not important in the design process.	Strongly Disagree	1 5	2	3	4	Strongly Agree
15.	Considering local context (i.e., current uses of the project site, opinions of those affected by the projects, etc.) during the design process is important.	Strongly Disagree	1 5	2	3	4	Strongly Agree
16.	Transdisciplinary knowledge is typically generated by experts working alone.	Strongly Disagree	1 5	2	3	4	Strongly Agree
17.	Academics and non-academics should collaborate to create transdisciplinary knowledge for community-based design projects.	Strongly Disagree	1 5	2	3	4	Strongly Agree
18.	Learning from others is not important when creating transdisciplinary knowledge.	Strongly Disagree	1 5	2	3	4	Strongly Agree
19.	When creating transdisciplinary knowledge, information from academics and non-academics should be valued equally.	Strongly Disagree	1 5	2	3	4	Strongly Agree

20. In your project you used a transdisciplinary approach in a design project with a local school, how might you use this type of approach in the future?

Thank you for your responses!

Appendix C: Pre- and post-reflections

Pre-Reflection

Introduction - Critical reflection is the part of experiential learning that generates, deepens, and documents learning. When used in this capacity, it needs to be understood not as touchy-feely, non-grade-able, private, stream-of-consciousness, but rather as a reasoning process that is analytical, integrative, assessable, subject to public critique, and structured/guided. While reflection is not about generating one right answer, not all reasoning is equally valid. Reflection can be used to support learners in making reasoned judgments that are well-supported with evidence and that result from consideration of multiple perspective—not merely expressing opinions.

Framework - Reflect upon activities from previous classes and in one page, summarize what you have learned about the transdisciplinary knowledge, include a definition, interactions, and actors that should be involved—use your own words. Explain the benefits to this type of knowledge production. Include two ways in which you will approach the class design projects in order to produce transdisciplinary knowledge.

Rubric

Criteria	Unacceptable	Marginal	Superior
Definition	0 pts - A definition is not provided. Response does not demonstrate critical thought.	3 pts - A marginally clear, concise, and accurate definition is provided. Response demonstrates some critical thought.	5 pts - A clear, concise, and accurate definition is provided. Response demonstrates critical thought.
Interactions	0 pts - Interactions involved in creating transdisciplinary knowledge are not identified. Response does not demonstrate critical thought.	5 pts - Interactions involved in creating transdisciplinary knowledge are marginally identified. Response demonstrates some critical thought.	10 pts - Interactions involved in creating transdisciplinary knowledge are fully identified. Response demonstrates critical thought.
Actors	0 pts - Actors involved in creating transdisciplinary knowledge are not identified. Response does not demonstrate critical thought.	5 pts - Actors involved in creating transdisciplinary knowledge are marginally identified. Response demonstrates some critical thought.	10 pts - Actors involved in creating transdisciplinary knowledge are fully identified. Response demonstrates critical thought.
Benefits	0 pts - Examples are not provided. Response does not demonstrate critical thought.	5 pts - Marginal examples are provided regarding the benefits to this type of production. Response demonstrates some critical thought.	10 pts - Specific examples are provided regarding the benefits to this type of production. Response demonstrates critical thought.
Application	0 pts - Examples are not provided. Response does not demonstrate synthesis and critical thought.	5 pts - Marginal examples are provided regarding the application of a transdisciplinary approach in the class design project. Response demonstrates some synthesis and critical thought.	10 pts - Two specific examples are provided regarding the application of a transdisciplinary approach in the class design project. Response demonstrates synthesis and critical thought.
Presentation & Polish	0 pts - Response does not demonstrate professionalism and/or synthesis of knowledge gained.	3 pts - Response demonstrates marginal professionalism and synthesis of knowledge gained.	5 pts - Response demonstrates professionalism. It is concise, clear and demonstrates a synthesis of knowledge gained.

Post-Reflection

Introduction - Critical reflection is the part of experiential learning that generates, deepens, and documents learning. When used in this capacity, it needs to be understood not as touchy-feely, non-grade-able, private, stream-of-consciousness, but rather as a reasoning process that is analytical, integrative, assessable, subject to public critique, and structured/guided. While reflection is not about generating one right answer, not all reasoning is equally valid. Reflection can be used to support learners in making reasoned judgments that are well-supported with evidence and that result from consideration of multiple perspective—not merely expressing opinions.

Framework - In 1-2 pages, answer the following prompts related to applying a transdisciplinary approach to solving water sustainability issues in local design projects.

- What is transdisciplinary knowledge, and why would this concept be taught to students working with communities?
- Using specific examples, explain how its components will be applied in your context?
- What barriers have you experienced in trying to use transdisciplinary approaches in your project setting?
- What strategies do you have for overcoming these barriers and continuing to use a transdisciplinary approach to solving water sustainability issues in local design projects?

Rubric

Criteria	Unacceptable	Marginal	Superior
Definition	0 pts - A definition is not provided. Response does not demonstrate critical thought.	3 pts - A marginally clear, concise, and accurate definition is provided. Response demonstrates some critical thought.	5 pts - A clear, concise, and accurate definition is provided. Response demonstrates critical thought.
Justification	0 pts - A justifiable argument is not provided. Response does not demonstrate critical thought.	5 pts - A marginally justifiable argument is provided for teaching this concept to students. Response demonstrates some critical thought.	10 pts - A synthesized, justifiable argument is provided for teaching this concept to students. Response demonstrates critical thought.
Application	0 pts - Examples are not provided. Response does not demonstrate critical thought.	5 pts - Marginal examples are provided regarding application in context. Response demonstrates some critical thought.	10 pts - Specific examples are provided regarding application in context. Response demonstrates critical thought.
Barriers	0 pts - Examples are not provided. Response does not demonstrate synthesis and critical thought.	5 pts - Marginal examples are provided regarding barriers in using a transdisciplinary approach in the class design project. Response demonstrates some synthesis and critical thought.	10 pts - Specific examples are provided regarding barriers in using a transdisciplinary approach in the class design project. Response demonstrates synthesis and critical thought.
Strategies	0 pts - A complete list is not provided. Response does not demonstrate synthesis and critical thought.	5 pts - A marginally complete list of steps necessary to overcoming barriers is provided. Marginal examples are provided. Response demonstrates some synthesis and critical thought on personal experience thus far.	10 pts - A complete list of steps necessary to overcoming barriers is provided. Specific examples are provided. Response demonstrates synthesis and critical thought on personal experience thus far.

Presentation & Polish	0 pts - Response does not demonstrate professionalism and/or synthesis of knowledge gained.	3 pts - Response demonstrates marginal professionalism and synthesis of knowledge gained.	5 pts - Response demonstrates professionalism. It is concise, clear and demonstrates a synthesis of knowledge gained.
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