Interdisciplinary Journal of Environmental and Science Education
2025, 21(4), e2517
e-ISSN: 2633-6537
https://www.ijese.com/

MODESTUM

Research Article

OPEN ACCESS

Transdisciplinary orientation scale scores as an indicator of undergraduate environmental course capacities development

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Citation: Azzarello, C. B., Vincent, S., Manzanares, A., Anderson, S., Romulo, C., Druckenbrod, D., & Knobloch, N. (2025). Transdisciplinary orientation scale scores as an indicator of undergraduate environmental course capacities development. *Interdisciplinary Journal of Environmental and Science Education, 21*(4), e2517. https://doi.org/10.29333/ijese/16900

ARTICLE INFO

Received: 01 May 2025
Accepted: 25 Aug. 2025

ABSTRACT

The demand for interdisciplinary environment and sustainability (IES) education is increasing because these programs prepare students to become professionals who can help solve interdisciplinary complex environmental and sustainability problems. In this article, we report on an unexpected observation we discovered when collecting student data for a project to help environmental programs evaluate student knowledge of complex food-energy-water systems (NSF award 2013373). Our sample of 114 students enrolled in entry-level IES courses across 10 diverse institutions of higher education revealed uniformly self-reported high scores on a validated measure titled the transdisciplinary orientation (TDO) scale. The scale measures the values, attitudes and beliefs; conceptual skills and knowledge; and the behavioral repertoires that predispose an individual to collaborating effectively in inter-/transdisciplinary research teams. Higher scores on the scale were significantly correlated with publication of interdisciplinary research articles with higher potential societal impact as judged by independent raters, and higher scores were associated with experience in transdisciplinary research. We explored correlations of the TDO scores with the students' characteristics and discussed the use of the TDO as an assessment tool for environmental curricula and courses.

Keywords: environmental education, sustainability education, curriculum assessment, STEM

INTRODUCTION

There is an increasing demand for interdisciplinary, transdisciplinary, and integrative professionals, particularly those with expertise in research integration and implementation to tackle complex environmental and sustainability problems (Bammer et al., 2020; Harris et al., 2010; Ledford, 2015; Uzzi et al., 2013). To meet this workforce development need, the number of interdisciplinary environment and sustainability (IES) degree-granting programs in higher education have expanded rapidly (Boone et al., 2023). IES programs–programs named environmental science, environmental studies, sustainability, natural resources, environmental policy and a variety of other names–utilize an interdisciplinary holistic approach to the interfaces between human and natural systems (Cooke & Vermaire 2015; Vincent & Focht, 2011; Wallace & Clark 2018). Three censuses of IES programs conducted in 2008, 2012, and 2016 by the National Council for Science and the Environment (now the Global Council for Science and the Environment) documented rapid growth in the number of IES programs–from 840 degree-granting programs in 2008, to 1,151 in 2012 and 1,361 in 2016 (Vincent et al., 2017). The 2016 census identified 2,361 IES degrees and an additional 2,222 degrees in a variety of disciplines and professional fields with formal specializations in environment, sustainability, natural resources and energy.

In this article, we report on an unexpected observation we discovered when collecting student data for a National Science Foundation (NSF) funded project: Developing a next generation concept inventory (NGCI) to help environmental programs evaluate student knowledge of complex food-energy-water systems (NSF award 2013373) (Horne et al., 2024; Royse et al., 2024). Our sample of 114 students enrolled in entry-level IES courses across 10 diverse institutions of higher education revealed uniformly self-reported high scores on a validated measure titled the transdisciplinary orientation (TDO) scale (Misra et al., 2015).

Interdisciplinary Attitudes in STEM Undergraduates

Understanding undergraduate attitudes toward interdisciplinary education is essential for interpreting their development of transdisciplinary capacities, such as those captured by the TDO framework. The TDO emphasizes epistemic humility, integrative thinking, and a commitment to collaborative problem-solving TDO qualities that are intentionally fostered through interdisciplinary engagement (Misra et al., 2015). Prior research underscores that exposure to multiple perspectives and the use of systems thinkingTDOapproaches that focus on the interconnections among components rather than isolated partsTDOare fundamental to cultivating these orientations (Augsburg, 2014; Knobloch et al., 2020). Through interdisciplinary education, students learn to envision the bigger picture, seeing how domains like food, energy, and water interact, thereby strengthening their ability to think across traditional boundaries (Augsburg, 2014; Knobloch et al., 2020).

Developing both systems thinking and interdisciplinary attitudes is critical because each supports distinct but complementary aspects of transdisciplinary readiness. Systems thinking equips students to understand the complexity and interdependence of global challenges, while interdisciplinary attitudes foster openness to multiple perspectives, intellectual risk-taking, and a sense of social responsibility TDO key traits associated with transdisciplinary collaboration (Augsburg, 2014; Guimarães et al., 2019; Vargas-Madrazo, 2018). Indeed, students who demonstrate interdisciplinary attitudes often exhibit epistemological awareness, a key predictor of integrative thinking (Vargas-Madrazo, 2018).

Students' progress through stages of choice, navigation, and integration as they deepen their interdisciplinary engagement, suggesting that developing these tools meaningfully impacts their ability to tackle complex problems (Bettencourt et al., 2022). Interest in interdisciplinary education is particularly strong when curricula address urgent global issues, such as nutrition and water sustainability (DiBenedetto et al., 2016) and fostering interdisciplinary attitudes has been shown to increase STEM students' willingness to pursue interdisciplinary coursework (Gero, 2017). This growing evidence points to the importance of intentionally developing these perspectives to prepare students for real-world problem solving.

Environmental attitudes provide another meaningful lens through which to examine transdisciplinary potential, as they reflect broader value systems and sensitivities toward complexity and integration. For instance, environmental studies students tend to hold more biocentric worldviews compared to broader student populations, who often display more utilitarian views (Evert et al., 2021; Schultz et al., 2010). Gender differences are also notable, with women more frequently demonstrating heightened environmental sensitivity (Evert et al., 2021), further suggesting that demographic and experiential factors shape students' development of transdisciplinary dispositions.

Overall, the value of cultivating inter- and transdisciplinary perspectives supports the relevance of the TDO framework for capturing the complex, multidimensional nature of undergraduate readiness for transdisciplinary work. It also highlights the need for educational strategies and assessment tools TDO such as the TDO scale TDO that intentionally foster and measure growth across the cognitive, behavioral, and affective domains critical for collaborative, integrative problem-solving.

The Transdisciplinary Orientation Scale

The TDO scale operationalizes conceptions of TDO the intrapersonal, interpersonal and intellectual orientations of individuals related to the collaborative success of interdisciplinary teams (Misra et al., 2015). Misra et al.'s (2015) research on development of the TDO metric revealed a two-factor correlated model with two dimensions: the VAB dimension and the CSB dimension. The VAB dimension includes a predisposition towards collaboration; openness towards learning other paradigms and worldviews; willingness to invest time in learning about fields other than one's own and to tackle complex problems; and beliefs about the benefits of collaboration compared with the extra time and effort. The CSB dimension includes the ability to approach problems holistically from different vantage points; integrate concepts across perspectives; and communicate effectively with colleagues having other perspectives. Mirsa et al. (2015) validated the scale using a sample of academics and researchers. In addition to this validation, they found that higher scores on the scale are significantly correlated with experience in transdisciplinary research teams and with the successful publication of interdisciplinary research articles with higher potential societal impact, as judged by independent raters. One of the authors of this paper, Dr. Vincent, has effectively used the TDO scale as an assessment tool for several NSF projects focused on increasing inter-/transdisciplinary capacities in undergraduate and graduate students, documenting that participation in the programs significantly increased students' TDO scores (NSF awards 1444758, 2022055, 2022190, 1828902, 1545404; Pennington et al., 2022; Vincent et al., 2023). TDO scores are calculated by coding the Likert scale responses to each of the 12-item scale questions and adding them together to provide an overall score. For example, using a coding scheme of Likert scale responses from 1-7, the highest maximum score would be 84.

For the NGCI project, we included the TDO scale questions in students' pre-interview questionnaires to investigate whether differences in TDO scores may be related to differences in students' interview answers to questions assessing their knowledge of Food-Energy-Water-Systems concepts.

MATERIALS AND METHODS

Sample

A volunteer and purposive strategy was used to recruit 10 IES programs from higher education institutions for the NGCI study. Initially, programs were recruited by personal contacts. During a second round of recruitment, specific programs were selected to ensure the sample was representative of institutional primary Carnegie classifications: baccalaureate colleges (3), master's colleges and universities (3), and

Table 1. Student characteristics (n = 114)

Characteristic	%
Gender	
Male	31
Female	63
Non-binary	4
Other	2
Age	
17-19	37
20-25	58
26-30	3
30+	2
Academic status	
Freshman	26
Sophomore	24
Junior	24
Senior	24
Graduate	3
Race/ethnicity	
American Indian or Alaskan Native	0
Asian or Asian American	12
Black or African American	4
Hispanic or Latino/a/x	4
Middle Eastern or North African	1
White or Caucasian	70
More than one race	8
Major	
Agriculture & natural resources	49
Social science & humanities	18
Science and math	17
Arts	4
Business & economics	6
Engineering & technology	2
Other	4
Institution	
California Polytechnic University	14
Northern Arizona University	11
Plymouth University	15
Rider University	7
Skidmore College	9
Smith College	8
St. Mary's College	12
University of Kansas	9
University of Northern Colorado	5
University of South Dakota	10
Type of environmental courses taken	
Environmental studies	53
Environmental science	62
Both environmental studies and environmental science	35
Neither environmental studies nor environmental science	19

Note. *Percentages may not equal 100% due to rounding

doctoral/research universities (4); and diverse types of IES degree-granting programs and the degrees they offer: environmental studies (5), environmental science (3), sustainability (3), policy and management (3) and environmental geoscience (1). Interviews were conducted with 114 students before, during and after completion of introductory entry level environmental courses (for more information about the interview process see Horne et al., 2024). The interviewed students completed a Qualtrics™ survey prior to the interviews to collect demographic data and other characteristics such as major, and data on which types of courses they have taken (selected yes or no for a variety of course types such as environmental studies, environmental sciences, biology, chemistry, etc.). The characteristics of the sample are shown in **Table 1**. Also included in the survey questionnaire were the 12 questions comprising the TDO scale (**Table 2**). A sample size of 114 is sufficient to measure correlations between attributes with a power of 0.70 to detect an effect size of 0.25 at $\alpha = 0.05$ (two-tailed).

The TDO Scale

The TDO consists of two subscales of six questions each that measure items related to the VAB dimension and the CSB dimension. The wording of the scale items was modified slightly to align with the context of undergraduate education. For example, instead of "My research to date reflects my openness to diverse disciplinary perspectives when analyzing particular problems." We used "My studies and research to date reflects my openness to diverse disciplinary perspectives when analyzing particular problems." We also modified the scale from a five-point Likert scale to a seven-point scale adding "slightly disagree" and "slightly agree" (strongly disagree, disagree, slightly disagree, neutral-not sure, slightly agree, agree, strongly agree) to increase the sensitivity of scores. The reliability of the modified 12-item scale is $\alpha = 0.90$; Mean [M] = 72.46; standard deviation [SD] = 8.6, very similar to the reliability of the original scale ($\alpha = 0.93$).

We coded students' TDO questions answers as 7 = strongly agree, 6 = agree, 5 = slightly agree, 4 = neutral, 3 = slightly disagree, 2 = disagree, 1 = strongly disagree. The maximum score for the VAB and CSB dimensions was 42 and 84 for the overall TDO score. Statistical analyses were conducted using SPSS 23 software.

RESULTS

This sample of 114 students enrolled in 10 different entry level environmental courses at 10 different colleges and universities had consistently high TDO scores, representing 88% of the score possible for the VAB dimension, 83% of the CSB dimension, and 87% of the overall TDO score (**Table 2**).

Mean TDO scores were high across all the students and differences in scores were not correlated with institution, gender, race/ethnicity, or major. However, TDO scores were significantly correlated with academic status. Freshmen had the lowest scores and juniors and seniors had the highest scores. We also noted that students who reported having taken at least one environmental studies course and one environmental science course had higher scores than students that had taken only one of these two types of courses or students who had not taken either type of course. We discuss possible explanations for this observation and the use of the TDO scale as an assessment tool.

The results were consistent for all ten introductory courses across institutions but were higher than the scores seen in several NSF-funded projects evaluated by a co-author. For example, in the assessment of 48 undergraduate students (sophomores, juniors and seniors) representing diverse majors and levels of academic status in the interdisciplinary research undergraduate program that was part of a sustainability research network project (Award 1444758), the students'

Table 2. Students' TDO scores (n = 114)

TDO question	Score μ
VAB questions	
My studies and research to date reflect my openness to diverse disciplinary perspectives when analyzing particular problems.	6.2 (SD = .94)
My studies and research to date reflect my interest in learning about new disciplinary concepts and theories in addition to the ones I'm most familiar with.	6.2 (SD = .94)
My studies and research to date reflect my interest in learning about new research methods that are different from the ones I am most familiar with.	5.7 (SD = 1.14)
I would describe myself as someone who values interdisciplinary collaboration.	6.5 (SD = .90)
I am willing to invest the time required for learning about fields different from my own.	6.2 (SD = 1.04)
I enjoy tackling the challenges posed by working on complex problems, even if doing so requires me to expend extra time and effort.	6.2 (SD =.95)
CSB questions	
I generally approach scientific problems from a multi-level perspective that encompasses both micro-and macro-level factors.	5.8 (SD = 1.15)
My studies and research to date reflect my ability to conceptualize complex problems by identifying various situation-specific factors that account for these problems.	6.0 (SD = 1.02)
My studies and research to date reflect my ability to create conceptual frameworks that bridge multiple fields.	5.8 (SD = 1.25)
My studies and research to date reflect my ability to think broadly about complex problems.	6.3 (SD = .68)
In my own work, I incorporate perspectives from fields that are different from my own.	5.8 (SD = 1.16)
In my own studies and research, I use research methods drawn from more than one discipline rather than relying exclusively on a single disciplinary approach.	5.8 (SD = 1.21)
VAB dimension	37 (SD =4.51)
CSB dimension	35 (SD = 4.81)
Total summed TDO score	73 (SD = 8.58)

Note. *Scale: 7 = strongly agree, 6 = agree, 5 = slightly agree, 4 = neutral, 3 = slightly disagree, 2 = disagree, & 1 = strongly disagree

Table 3. VAB, CSB, and TDO scores by academic status

Academic status	VAB score μ	CSB score μ	TDO score μ
Freshman (n = 30)	35	33	68
Sophomore (n = 27)	37	35	72
Junior (n = 27)	39	37	76
Senior (n = 27)	38	37	75
Graduate (n = 3)	38	35	72

Table 4. VAB, CSB, and TDO scores by student age

Age	VAB score μ	CSB score μ	TDO score μ
17-19 (n = 41)	35	33	69
20-25 (n = 54)	38	37	75
26+ (n = 5)	38	36	74

scores before participation were 83% for VAB, 63% for CSB and 73% for TDO. After participation the students in this program saw significant gains in VAB (92%) and overall TDO (79%). Assessments of graduate students in the NRT programs likewise showed significant gains from participation in the program, with lower pre-participation scores than the scores seen in the students in this observation. The students in these projects represented diverse majors and may not have taken environmental courses prior to their participation in the projects.

We ran Kruskal-Wallis tests for differences between groups and found no correlations between VAB, CSB, and TDO scores based on institution/course, major, gender, or race/ethnicity.

Significant differences in scores were found for students' academic status and age. Scores were significantly higher for juniors and seniors compared with freshmen and sophomores ($H[3] = 12.02$, $p = .007$ for VAB, $H[3] = 10.83$, $p = .013$ for CSB, and $H[3] = 11.99$, $p = .007$ for TDO; **Table 3**). Graduate student scores were not higher than juniors and seniors, but only three students were in this category. We also noted significant differences based on student age with older students having higher scores than younger students ($H[2] = 8.9$, $p = 0.12$ for VAB, $H[2] = 11.48$, $p = .003$ for CSB, and $H[2] = 11.31$, $p = .003$ for TDO; **Table 4**). Three students did not provide their age.

Students who had taken both environmental studies and environmental science(s) courses (yes/no answers for each type) had significantly higher VAB, CSB, and TDO scores than students who had only taken one type of environmental course ($H[2] = 5.96$, $p = .051$ for VAB, $H[2] = 6.81$, $p = .033$ for CSB, and $H[2] = 6.86$, $p = 0.32$ for TDO). However, students who had not taken either type of course had higher average scores than students who had taken one type of course (**Table 5**). Given the significant correlations of higher scores with higher academic status and age, the percentage of each group's academic status and age could have been a factor. This does not appear to be the case since the group of students with no coursework has fewer juniors and seniors than the other two groups (33% versus 48% and 53%, respectively) and the age proportions for each group are similar. Since the both-course-type-group has a higher proportion of juniors and seniors than the only-one-type-course group that could be a factor in the differences seen between these two groups.

DISCUSSION

To our knowledge, the TDO scale has not been used in environmental course assessment or degree program assessment. The results of this study indicated a positive significant correlation between increased exposure to environmental courses and higher TDO scores, suggesting that such coursework may contribute to TDO development. This could be due to several reasons as we did not identify causes of TDO development. For example, undergraduate students may be more epistemologically aware (Vargas-Madrazo, 2018) when engaged in urgent global issues (DiBenedetto et al., 2016) as they grow in their TDO with guided educational

Table 5. VAB, CSB, and TDO scores by types of environmental courses taken

Academic status	VAB score μ	CSB score μ	TDO score μ	Academic status	Age
Neither type of course (n = 22)	36	36	73	27% Freshmen 41% Sophomore 14% Junior 9% Senior 9% Graduate	33% 17-19 57% 20-25 10% 26+
Environmental science(s) or environmental studies (n = 52)	36	34	71	25% Freshmen 27% Sophomore 19% Junior 27% Senior 2% Graduate	35% 17-19 58% 20-25 2% 26+
Both environmental studies and environmental science(s) (n = 40)	38	37	75	28% Freshmen 10% Sophomore 35% Junior 18% Senior 0% Graduate	35% 17-19 60% 20-25 5% 26+

experiences in environmental sciences or studies. Or undergraduate students may be more open and willing to engage in interdisciplinary courses when they develop interdisciplinary attitudes (Gero, 2017). As such, the students who enrolled in IES programs and courses may be more motivated to conduct interdisciplinary study and research (Guimarães et al., 2019) and therefore would likely have higher VAB scores than other students because of their personal belief in the value of interdisciplinary work. They may also have higher CSB scores due to seeking out interdisciplinary study and research experiences. Whether implicitly or explicitly, students enrolled in environmental courses may be more inclined to value interdisciplinarity and seek out interdisciplinary experiences.

The consistency of high mean scores across students in 10 different IES courses at 10 different colleges and universities was unexpected because of the diversity of types of IES-degree granting programs, degrees offered, and institutional classifications. The findings of significant correlations with academic status, age and that students took both types of courses versus one type or none had higher scores suggested that more exposure to concepts included in the TDO scale increased scores. While this observation suggests that students enrolled in environmental courses tend to have higher TDO scores, it remains unclear whether this is due to the courses themselves, being engaged in solving urgent global issues with peers beyond the courses, or if students with inherently higher TDO scores are more likely to self-select into these courses. Regardless, we remain confident in the validity of the TDO scale as an assessment tool because it has demonstrated strong psychometric properties across multiple studies (e.g., Misra et al., 2015) and was designed to capture stable orientations rather than program-specific variations; however, we acknowledge that complementary qualitative or mixed approaches could provide valuable insights into how participants interpret and enact these orientations in different contexts.

Further research is still needed to determine the usefulness of the TDO scale in curriculum design and course assessment and whether more exposure to environmental courses, in general, or specific strategies (i.e., solving urgent global problems) with courses increase the TDO (VAB and CSB) of IES majors and minors as well as other majors who have IES specializations and take environmental courses.

The students in the sample group may have reported consistently high scores because they don't have enough familiarity with the concepts in the TDO scale questions to answer them accurately, or because they believed more agreement with the concepts would be viewed positively by the researchers and/or their instructors.

The key takeaway from this study is that across many U.S. institutions TDO scores remained consistent in interdisciplinary environmental courses, which highlights the potential use of the TDO to assess the value of interdisciplinary courses in developing interdisciplinary/TDO and the potential value of integrating environmental education into broader curricula. One could raise the question that the consistently high TDO scores across interdisciplinary environmental courses could indicate stagnation, or perhaps it could indicate consistency in how learning outcomes and teaching strategies in environmental courses may contribute to interdisciplinary orientations. It remains unclear whether students with higher TDO scores are naturally drawn to these courses or if the courses themselves contribute to TDO development. It is important to note that this study is observational in nature and relies on secondary data not originally collected with this specific research question in mind. The results provide preliminary evidence of a meaningful relationship between environmental coursework and TDO, offering a valuable foundation for future research in this area.

CONCLUSION

The self-reported nature of the TDO scale responses introduces the possibility of response bias, including social desirability bias and limited comprehension of the scale's constructs. In evaluation processes, Dr. Vincent has students answer the TDO scale questions in an entry survey and then in subsequent surveys asks them to retrospectively answer the questions before their participation in the program and after. The students' retrospective before-participation scores are somewhat lower from the entry surveys in subsequent surveys, indicating that they understand the concepts better through

participation in the programs. This suggests that engagement with interdisciplinary programs may enhance students' understanding of transdisciplinary constructs over time.

In any future studies, we recommend asking students how many environmental courses they have taken, as our findings indicate that more exposure to environmental courses may correlate with higher TDO scores. An interesting trend in our data suggests that repeated engagement with environmental content, which often involves grappling with complex, real-world problems, may naturally foster transdisciplinary thinking. However, because we did not directly measure prior coursework or other formative experiences, this relationship cannot be confirmed with certainty. Future studies could address this limitation by explicitly tracking students' course histories and exploring epistemological awareness and beliefs of students who hold interdisciplinary attitudes (Vargas-Madrazo, 2018). These approaches would help map the development of interdisciplinary attitudes based on VAB, CSB, and TDO scores, while also informing potential interventionsTDOsuch as scaffolded interdisciplinary curriculaTDOthat might strengthen these orientations over time.

This study highlights the potential role of environmental curricula in fostering transdisciplinary thinking and underscores the utility of the TDO scale as an assessment tool. It also calls attention to the need for future research that disentangles the effects of programmatic exposure from self-selection, particularly in understanding the developmental trajectory of students' TDO.

Author contributions: CBA, SV, AM, SA, CR, DD, & NK: contributed equally to conceptualization, data curation, formal analysis, methodology, resources, validation, visualization, writing – original draft, writing – review & editing; **CBA & CR:** project administration. All authors agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that the study was conducted in accordance with ethical standards for research involving human participants. All procedures were reviewed and approved by the Institutional Review Board (IRB) of the University of Northern Colorado (Protocol #2013373). The authors further stated that informed consent was obtained from all participants prior to data collection, and participation was voluntary. All data were anonymized to ensure confidentiality, and no personally identifiable information was collected or reported.

AI statement: The authors stated that no generative AI or AI-based tools were used during any part of the research or manuscript writing.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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