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The development and evaluation of interdisciplinary STEM, sustainability, and management curriculum

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A R T I C L E I N F O

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Sustainability
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A B S T R A C T

There is an increasing need in the workforce for STEM and sustainability literate graduates. In practice, however, it is difficult to enact interdisciplinary STEM and sustainability curriculum, particularly in business disciplines. To address this gap, we designed, developed, implemented, and evaluated an interdisciplinary STEM, sustainability, and management course called *Applied Organizational Sustainability* using the ADDIE (analyze, design, develop, implement, evaluate) model for instructional design. We used a robust multi-method evaluation that includes pre-/post-tests and treatment/control groups to longitudinally assess changes in student sustainability knowledge. Quantitative results indicate significant improvement in three of the four sustainability knowledge measures for treatment students but not for control students. Qualitative results from a focus group indicate that (1) content was new to business and management students, (2) students found the content to be relevant to employment, and (3) students viewed the content as valuable to university curriculum. These results provide research-based support for the adaptation and expansion of interdisciplinary STEM and sustainability curriculum in higher education, including adaptation of *Applied Organizational Sustainability*, its modules, and/or its assignments.

High-profile organizations recognize the need for improved undergraduate science, technology, engineering, and math (STEM) education (Borrego & Henderson, 2014). The call corresponds with the increased frequency and intensity of complex challenges organizations are facing, many of which require managers and workers to apply STEM skills (Bagley, Sulkowski, Nelson, Waddock, & Shrivastava, 2020; U.S. Department of Education, 2020). Further, businesses and industries are often engaged in sustainability agendas which require knowledge of sustainability precepts and goals (Allen, 2016; Bagley et al., 2020; McCarthy & Eagle, 2021; Theis & Tomkin, 2015). Taken together, there is growing demand for integrated STEM and sustainability competencies among college graduates (e.g., Avelar, da Silva-Oliveira, & da Silva Pereira, 2019; Bagley et al., 2020).

However, interdisciplinary business and management curriculum that incorporates STEM and sustainability is lacking (Petrun Sayers et al., 2020). Answering calls to enhance workforce STEM and sustainability preparedness (e.g., Bagley et al., 2020; Smith & Watson, 2019; U.S. Department of Education, 2020), we designed, developed, implemented, and evaluated an interdisciplinary STEM-based management course called *Applied Organizational Sustainability* using the ADDIE model of instructional design (Chevalier, 2011). The ADDIE (analysis, design, develop, implement, evaluate) aligns a training function (e.g., STEM and sustainability contents

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and materials) to improve a prescribed measure of student performance (Chevalier, 2011). In the analysis phase of the ADDIE, we identified the Sustainability Knowledge Assessment (ASK; Zwickle, Koontz, Slagle, & Bruskotter, 2014) to measure student sustainability learning. The ADDIE model is widely applicable to instructional design because it provides a step-by-step, systematic framework that is easy to use and appropriate for a variety of educational settings (e.g., online, blended, or live delivery modalities) (Peterson, 2003). Utilizing the ADDIE, we hypothesize we will observe improved sustainability learning for students participating in the curriculum.

Looking forward, we overview literature related to STEM and sustainability in management education followed by description of the ADDIE steps we used for interdisciplinary instructional design. We offer our hypothesis. We then present methods, results and analysis, and discussion sections.

1. STEM and sustainability in management education

According to Smith and Watson (2019, p. 17), "STEM [education] can and should provide critically important skills and insights into alternative futures as ways forward for economic, social, and environmental sustainability." In turn, managers and workers can critically apply STEM skills and insights to address challenging tasks faced by organizations and societies (U.S. Department of Education, 2020). This is particularly true for grand sustainability challenges like climate change that require widespread, collaborative attention and a complex understanding of socioecological system interconnectedness (Bansal, Grewatsch, & Sharma, 2021; George, Howard-Grenville, Joshi, & Tihanyi, 2016; Whiteman, Walker, & Perego, 2013). We advocate for the strong conception of sustainability, which is an integrative and balanced approach that allows for minimal trade-offs between economic, social, and environmental concerns (Theis & Tomkin, 2015). Conversely, managers who enact weak sustainability demonstrate "little to no concern for an organization's impact on the wider socioecological system" (Andre, 2020, p. 768). Weak sustainability entails managers and organizations favoring a component area (e.g., economic profitability) often to the detriment of others (e.g., environmental injustices like air pollution that inequivalently threaten local societies) (Theis & Tomkin, 2015).

Educators from management and other disciplines are committed to preparing students for a sustainable future, with some actively integrating experiential sustainability problem-solving and decision-making into their courses (e.g., Andre, 2020; Cole & Snider, 2019; Sroufe, 2020; Thomassen & Jorgensen, 2020; Urdan & Luoma, 2020; Wade & Piccinini, 2020). Management students are also taking stand-alone sustainability courses as (1) elective courses outside of the management discipline, (2) elective courses within discipline, and/or (3) required courses within discipline (Bagley et al., 2020; Cole & Snider, 2019; Wu, Huang, Kao, & Wu, 2010). Management educators contend that sustainability curricula should be interdisciplinary (Andre, 2020; Annan-Diab & Molinari, 2017; Bagley et al., 2020; Craig, Petrun Sayers, Gilbertz, Karam, & Feng, 2021; Petrun Sayers et al., 2020), however, in practice such curricula is difficult to provide. For instance, when students take courses outside their discipline, instructors tend to convey disciplinary sustainability perspectives not consistent with the students' own understanding (Kurland et al., 2010). The disconnect creates disciplinary silos rather than a learning environment that fosters an integrative, discipline-spanning understanding of sustainability. Further, interdisciplinarity courses in management education are confined by a limited knowledge base about other specialized disciplines (e.g., STEM), and typical time constraints for curricular design and development (Annan-Diab & Molinari, 2017; Andre, 2020; Craig, Petrun Sayers, Gilbertz, Karam, & Feng, 2021).

Successfully blending STEM and sustainability education together requires students to apply STEM concepts to sustainability topics (Hopkinson & James, 2010; Smith & Watson, 2019). Yet, with few exceptions, the explicit and critical application of STEM knowledge and skills to sustainability problems or decisions in management education is rare (Association for the Advancement of Sustainability in Higher Education [AASHE], 2021; Petrun Sayers et al., 2020). For instance, Petrun Sayers et al., 2020 conducted a literature review finding no higher education studies in business or management disciplines that investigated STEM and sustainability simultaneously. *Applied Organizational Sustainability*, including course content, assignments, and evaluation results, provides guidance and examples for instructors and administrators seeking to implement STEM-focused, interdisciplinary sustainability curriculum.

2. ADDIE model for instructional design

We utilized the ADDIE model for instructional design as the framework to create the new *Applied Organizational Sustainability* course. The ADDIE model aligns a training function with a performance outcome (Chevalier, 2011). In our study, the *Applied Organizational Sustainability* course serves as the training function and the performance outcome is sustainability learning. Our evaluation design (i.e., the last ADDIE step) with pre- and post-tests allows us to investigate student sustainability learning for those who participated in the training function (i.e., treatment students) and those who did not (i.e., control students). Each of the sequential

Fig. 1. ADDIE model of instructional design (Cheveliar, 2011).

ADDIE steps is outlined in the remainder of this section (see Fig. 1).

2.1. Step 1: analysis

The analysis step of the ADDIE model assesses content and performance gaps to inform curricular design and development (Chevalier, 2011). Analysis took place prior to the creation of *Applied Organizational Sustainability.* First, Petrun Sayers et al., 2020 conducted a literature review finding no higher education studies in business or management disciplines that investigated STEM and sustainability simultaneously. Additionally, the review unveiled several weaknesses in evaluation designs in higher-education including lack of control groups and longitudinal designs. During the analysis stage, we also identified the focal performance measure, the Sustainability Knowledge Assessment (ASK; Zwickle et al., 2014). The ASK is a previously validated instrument created by an interdisciplinary team of sustainability educators that has been used to track university-level sustainability knowledge year-to-year at multiple higher-education institutions (Heeren et al., 2016; Zwickle et al., 2014). Zwickle et al. (2014) identified a student performance gap (i.e., <70% ASK aggregate student scores) when validating the instrument, further supporting the use of the instrument.

2.2. Steps 2 and 3: design and develop

The design step involves putting together a content outline for the training function, and the develop step requires the production of course content and materials based on prescribed content requirements (Chevalier, 2011). The two steps are closely related, and often happen in tandem. The design and development for the stand-alone *Applied Organizational Sustainability* course were primarily derived from four previously designed, developed, implemented, and evaluated interdisciplinary STEM and sustainability modules. The four modules were initially designed and developed to: (1) introduce sustainability as an integrated field that includes environmental, social, and economic components, (2) build students' STEM competencies with sustainability exercises requiring students to employ science, technology, engineering, and/or math in problem-solving activities, (3) establish the relevance of STEM-based sustainability competencies in business management contexts, and (4) reinforce a shared lexicon and skillset that students can use to "define, explain, and apply economic, environmental, and social components of sustainability using STEM-based evidence" (Craig, Petrun Sayers, Gilbertz, Karam, & Feng, 2021). Ultimately, each module was designed to fulfill specific learning objectives.

Three of the modules for *Applied Organizational Sustainability* were deployed in business (*Business & Environment*, *International Business*) and STEM-infused (*Human Geography*) courses at a regional university in the Western United States. A fourth module was deployed in a STEM course (*Applied Climatology*) at a large doctoral granting university in the Southeast United States. We deployed the four modules in 2018 and 2019, and evaluation results provide qualitative and quantitative research-based evidence of improved sustainability knowledge for students who received the modules, but no change for control students who did not participate in the curriculum (Craig, Petrun Sayers, Gilbertz, Karam, & Feng, 2021; Petrun Sayers et al., 2021). We designed and developed a fifth module, "Strategic Management Case for Sustainability," adding to the four existing modules. The fifth module is anchored by an interdisciplinary STEM and management teaching case (i.e., Craig, Petrun Sayers, Feng, & Kinghorn, 2019). See Table 1 for course-level learning objectives.

2.3. Step 4: implement

Applied Organizational Sustainability serves as an upper-level management elective for management students and as an upper-level business elective for other business majors. The pre-requisites include junior standing and prior completion of a junior-level *Principals of Management* course. *Applied Organizational Sustainability* consists of five modules, including four from the previously evaluated courses described above (see Table 2 for all the modules and assignment descriptions). We implemented online sections of the *Applied Organizational Sustainability* course at a public regional university in the Southeast United States in Fall 2019 and Fall 2020. The course was offered as an upper-level management elective with pre-requisites including junior standing and prior completion of a *Principles of Management* course. The location of implementation changed from the Western university due to an employment change for the instructor of record. To the best of our knowledge, *Applied Organizational Sustainability* is the first interdisciplinary STEM, sustainability, and management course designed, developed, and implemented for undergraduate business and management students.

Table 1
Course learning objectives.
Upon completion of the course students will be able to.

Learning Objective 1[a]	demonstrate an in-depth understanding of the economic, environmental, and social components of sustainability using STEM-based evidence;
Learning Objective 2	understand ways in which organizations address issues related to current economic, environmental, and social conditions;
Learning Objective 3	explain how the natural environment influences organizations using an applied approach; and
Learning Objective 4	utilize qualitative and quantitative techniques to address sustainability issues.

[a] Note. *Learning* Objective *1* is a course-level objective shared by all participating courses.

Table 2
Applied Organizational Sustainability module descriptions, readings, and assignments.

Module Name	Description	Course of Origin	Readings	Assignment Descriptions
Module I: Introduction to Sustainability and Sustainable Development	Module I (1) provides an introduction and overview of sustainability and sustainable development, (2) challenges students to apply math skills to assess local sustainability challenges, and (3) requires students to discuss the international implications of the UN Millennial Sustainable Development Goals.	Applied Organizational Sustainability International Business	Theis and Tomkin (2015); UN (2020)	Applied Exercise: Students first review chapters from an open-source sustainability text (Theis & Tomkin, 2015) about sustainability metrics and life-cycle analysis. They then provide a list of economic, environmental, and social metrics that are of importance when conducting a life-cycle analysis. Students also calculate the environmental impact (i.e., carbon emissions) of energy consumption given a scenario described in the exercise. Small Group Discussion: Students first review an introduction to sustainability chapter (Theis & Tomkin, 2015) and the United Nations (2020) Sustainable Development Goals (SDGs). The discussion requires students to identify the three most dire social challenges from the SDGs and identify what United States-based businesses can do to address the challenges.
Module II: The Geographic Case for Sustainability	Module II takes a geographic perspective to the most salient economic, environmental, and social sustainability challenges along the Yellowstone River Valley. The module is based on the book *An Introduction to Sustainability: The case of the Yellowstone River* (Gilbertz & Hall, 2022). The case requires students to demonstrate fluency in each STEM area. Module II requires students to complete a written assignment connecting sustainability challenges along the Yellowstone to comparable local and international challenges.	Human Geography	Gilbertz & Hall, 2022	Written Assignment: Students first review the case for sustainability on the Yellowstone River (Gilbertz & Hall, 2022). After covering the Montana-based case, they then conduct independent research to find comparable challenges in their home state and internationally, comparing and contrasting issues across three distinct geographic locations.
Module III: Modern Issues and Methods: Weather, Climate, and Sustainability	Module III requires students to utilize science, technology, and math knowledge and skills to investigate the sustainability implications of climate change. Specifically, students will (1) understand the distinctions between weather and climate change, (2) interface with technology to retrieve, manipulate, analyze, and interpret weather and climate data, and (3) discuss the effects of climate change on the three component areas of sustainability: economic, environmental, and social.	Applied Climatology	Reidmiller et al. (2018); Schmittner (2018)	Applied Exercise: Students first review climatology chapters about weather and climate (Schmittner, 2018). Given a PowerPoint with instructions on how to download weather/climate data, students then interface with the National Oceanic and Atmospheric Administration's (NOAA) website to retrieve data. They then scrub the data, run statistical analysis on the data, and analyze the results. An Excel template is provided with prefilled formulas to run the analysis once students input the weather/climate data. Small Group Discussion: Students first review the 4th National Climate Assessment (Reidmiller et al., 2018). Based on the report, they then (1) identify social, economic, and environmental risks and (2) respond to a groupmate's post about how they might be personally impacted by the risks.
Module IV: The Strategic Management Case for Sustainability	Module IV requires students to apply technology, environmental engineering, and math knowledge and skills. Specifically, students will use technological competencies to locate, manipulate, and analyze the	Applied Organizational Sustainability	Craig, Petrun Sayers, Feng, & Kinghorn, 2019; Ma et al. (2020)	Applied Exercise: Students are provided with sales data from a tourism business, and then use the technological assets from NOAA to retrieve weather/climate data at the focal business location to match with the sales data.

(*continued on next page*)

Table 2 (*continued*)

Module Name	Description	Course of Origin	Readings	Assignment Descriptions
	relationships that weather and climate share with business performance (i.e., tourism business sales). Based on statistical analysis, students will engage in environmental engineering by formulating responses to questions about strategic management from the Craig, Petrun Sayers, Feng, & Kinghorn, 2019 case.			The exercise requires students to analyze and interpret statistical relationships shared between business and weather/climate when answering the discussion questions. An Excel template is provided with business data and prefilled formulas to run the analysis once students input the weather/climate data. Written Assignment: Craig, Petrun Sayers, Feng, & Kinghorn, 2019 requires students to conduct a wSWOT, or a weather SWOT, analysis using the case of a small tourism business in Virginia Beach. Based on the case and results from the applied exercise, students then respond to discussion questions using the wSWOT framework.
Module V: The Management and Policy Case for Sustainability	Module V was developed based on one of the most salient sustainability-related challenges to the American West: Wildfire. The Craig (2019) case and accompanying documentary by the History Channel (2000)—*Escape: Fire on Mann Gulch*— about wildfire management requires students to apply environmental engineering knowledge and skills to formulate written responses to questions about wildland fire management and policy from a communicative perspective.	Business & Environment	Craig (2019); Bergmann, Stechemesser, and Guenther (2016); History Channel (2000); Thackaberry (2004)	Written Assignment: Craig (2019) is an environmental engineering-based case about wildland fire management, drought, policy, and sustainability. Discussion questions require students to consider the environmental, economic, and social implications of the case and also make managerial decisions pertaining to the natural environment.

*Note. In addition to the assignments outlined in the table, there are also graded quizzes for each reading and each applied exercise.

2.4. Step 5: evaluate

The last step of the instructional design process is evaluation. Petrun Sayers et al., 2020 conducted a literature review about STEM and sustainability curriculum in higher education which found that irrespective of discipline, most evaluation designs are (1) cross-sectional, (2) lacked treatment and control students, and (3) relied on single methods such as end-of-term student evaluations. Filho et al. (2021, p. 1) confirmed this finding, noting that "despite the fact that publications on matters related to sustainable development offer solid evidence of academic activity, there is a dearth of literature in this field." To address this knowledge gap, we utilized a robust longitudinal evaluation design (i.e., pre- and post-tests during Fall 2019 and 2020 terms) with treatment and control groups in addition to quantitative and qualitative measures. We used the ASK—a multi-question sustainability literacy instrument that assesses overall sustainability knowledge and the environmental, economic, and social sub-scales—to quantitively measure performance improvement. This type of assessment is known as data-based decision making, which often focuses on standardized performance assessments (Schildkamp, van der Kleij, Heitink, Kippers, & Veldcamp, 2020). Additionally, we include a qualitative perspective by conducting a focus group with students in the treatment condition. Measures are discussed in greater detail in the methods section.

The evaluation design (i.e., treatment/control groups, educational intervention, pre-/post-tests) allows us to test our hypothesis: *Sustainability knowledge will improve for treatment but not control students.*

3. Methods

3.1. Procedure and sample

Prior to conducting any evaluation tasks, we obtained institutional review board (IRB) approval. Quantitative evaluation was conducted using an online survey hosted by the Qualtrics platform at the beginning and end of the Fall 2019 and 2020 terms. The instructor emailed links to students to participate. Treatment courses included online sections of *Applied Organizational Sustainability* for Fall 2019 ($n = 9$) and 2020 ($n = 13$); control sections included an instructional television (ITV) section of *Strategic Management* and an online section of *Integrated Marketing Communication* for Fall 2019 ($n = 18$) and Fall 2020 ($n = 11$), respectively.

The control courses were chosen considering student make-up (i.e., upper-level business students) and delivery format (i.e., distant) to maximize comparability to *Applied Organizational Sustainability*. The control courses also did not explicitly cover STEM or sustainability topics. This is considered a quasi-experimental design because we were not able to randomize students into treatment and control courses (Gopalan, Rosinger, & Ahn, 2020). This design is common in educational research when random assignment into treatment and control courses is not possible. In total, 22 treatment students and 29 control students completed the pre- and post-tests ($n = 102$ total observations) for the quantitative portion of the evaluation. The treatment/control group, pre-/post-test evaluation design assesses the performance implications for business and management students enrolled in *Applied Organizational Sustainability* and students enrolled in the control courses. See Table 3 for demographics.

Additionally, we conducted a 60-min focus group ($n = 5$) October 2019 with currently enrolled *Applied Organizational Sustainability* students. The main purpose of formative pilot testing is to provide feedback that instructors can use to improve materials and/or content delivery. This formative approach is known as assessment for learning (or AFL), which focuses on learning processes rather than outcomes (Schildkamp et al., 2020). Formative assessment can also help students reflect on work completed to date, how they are progressing in a course, and acknowledge what is, and is not, working. To ensure student confidentiality and objectivity, an external evaluator with experience in qualitative methods conducted the focus group. Since the session was not recorded, a dedicated notetaker was also present in the session to capture participant responses. The course instructor assisted with recruitment by emailing information about the focus group to students. The evaluator hosted the synchronous focus group using Zoom.

3.2. Measures

3.2.1. Quantitative

The ASK (Zwickle et al., 2014) is a general sustainability assessment originally comprised of six environmental, five social, and five economic questions. Consistent with the original instrument, each question has one correct response, three incorrect responses, and an “I don’t know” response option. Percentage scores for ASK overall and subcategories were calculated by dividing the number of correct responses by the total number of questions. Because the instrument is balanced along the three sustainability dimensions, it can assess if student sustainability knowledge improvement is balanced (i.e., strong sustainability) or not (i.e., weak sustainability). Consistent with the most recent iteration of the ASK (Zwickle & Jones, 2018), there was a single *economic* question omitted “Which of the following is the primary reason that gasoline prices have risen over the past several decades in the USA?” See Table 4 for the complete list of questions.

3.2.2. Qualitative

Using a semi-structured discussion guide, the evaluator asked students to discuss (1) reasons for enrollment, (2) how the course incorporates sustainability into course design, (3) instructional design and technology, (4) suggestions for additional topics or issues, (5) overall course satisfaction, and (6) how course content is shaping their understanding of sustainability. The six discussion guide sections contained more probes to gather additional context if necessary. For example, in the second section, the evaluator asked: “Has this course discussed issues about sustainability?” Related probes included: “What topics were discussed?” and “How have businesses addressed environmental concerns and sustainability?” among others.

4. Analysis and results

4.1. Sustainability knowledge improvement

Using IBM SPSS v. 25, we first ran descriptives and correlations for each of the dependent variables sorted by treatment/control groups and pre-/post-tests (see Table 5). We also created graphic representations of changes for each dependent variable (see Fig. 2A-D). The pre-tests on the figures demonstrate baseline levels for treatment and control students, and post-tests the results at the end of the course. To determine if the mean changes (i.e., % score) to the ASK and its sustainability subcategories (i.e., environmental, social, economic) significantly improved, we used paired-sample t-tests (Table 6). Paired-sample t-tests represent a between group method, allowing us to determine if there were differences on ASK scores from pre-to post-tests for treatment and control students to test our hypothesis.

We calculated the minimum sample size for analysis (n) based on the observed standard deviations (sd) from Table 5, a large effect size ($d = .80$), a significance level of $\alpha = 0.05$, and a confidence interval of $CI = 0.05$ (University of San Francisco Clinical &

Table 3
Demographics.

Characteristics	Treatment (n = 22)	Control (n = 29)
Gender	40.9% Male, 59.1% Female	44.8% Male, 51.7% Female, 3.4% Other [not specified]
Age	Mean = 29.50 (range 20–53); Median = 26.5	Mean = 23.10 (range 20–47); Median = 22
Race	77.3% White, 22.7% Black or African American	86.2% White, 3.4% Black or African American, 10.3% Asian
Ethnicity	4.5% Latinx, Hispanic, or Spanish speaking background	6.9% Latinx, Hispanic, or Spanish speaking background
Party	54.3% Republican, 27.3% Democrat, 9.1% Independent, 9.1% Other	43.1% Republican, 25.9% Independent, 10.3% Democrat, 12.1% Libertarian, 8.6% Other
Grade	34.1% Junior, 65.9% Senior	3.4% Junior, 96.6% Senior
Employment	61.4% Full-Time, 20.5% Part-Time, 18.2% Not Employed	3.4% Full-Time, 60.3% Part-Time, 36.2% Not Employed

Table 4
Zwickle et al. (2014) Sustainability Knowledge Assessment (ASK) questions.

Environmental subcategory
What is the most common cause of pollution in streams?
Ozone forms a protective layer in the earth's upper atmosphere. What does ozone protect us from?
What is the name of the primary federal agency that overseas environmental regulation?
What is the primary benefit of wetlands?
Which of the following is an example of sustainable forest management?
In the USA, what do we currently do with the nuclear waste generated by nuclear power plants?
Social subcategory
Which of the following is the most commonly used definition of sustainable development?
The wealthiest 20% of people in the USA own approximately what percent of the nation's privately held wealth?
Over the past three decades, what has happened to the difference between the wealth of the richest and poorest Americans?
Higher levels of education generally lead to […]
Which of the following populations has the highest rate of growth?
Economic subcategory
Which of the following countries has now passed the USA as the biggest emitter of the greenhouse gas carbon dioxide?
Many economists argue that electricity prices in the USA are too low because […]
Which of the following is a leading cause of the depletion of fish stocks in the Atlantic Ocean?
Which of the following is the most commonly used definition of economic sustainability?

Table 5
Means, standard deviations, and correlations.

Variable	*M*	*SD*	1	2	3	4
Pre-test, treatment (n = 22)						
1 ASK	.59	.19	–			
2 ASK-Environmental	.67	.22	.90**	–		
3 ASK-Social	.65	.17	.78**	.54**	–	
4 ASK-Economic	.40	.29	.89**	.69**	.58**	–
Post-test, treatment (n = 22)						
1 ASK	.70	.18	–			
2 ASK-Environmental	.77	.22	.82**	–		
3 ASK-Social	.66	.23	.79**	.46*	–	
4 ASK-Economic	.63	.24	.70**	.38	.36	–
Pre-test, control (n = 29)						
1 ASK	.55	.22	–			
2 ASK-Environmental	.59	.29	.84**	–		
3 ASK-Social	.60	.23	.75**	.36	–	
4 ASK-Economic	.44	.28	.82**	.50**	.59**	–
Post-test, control (n = 29)						
1 ASK	.55	.25	–			
2 ASK-Environmental	.57	.28	.94**	–		
3 ASK-Social	.61	.26	.86**	.67**	–	
4 ASK-Economic	.45	.27	.87**	.76**	.62**	–

Translational Science Institute, 2022). Our n=22 for treatment students and n=29 for control students was larger than the pre-requisite n=20 pairs needed to reliably run paired-sample t-tests. Results demonstrate that treatment students significantly improved for the ASK ($t = -3.08(21)$ $p = .006$, +11%Δ), ASK-Environmental (t=(21) = 2.43, $p = .024$, +10% Δ), and ASK-Economic (t(21) = -4.63, p = .000, +23% Δ). However, there was not a significant change for the ASK-Social (t(21) = -.40, p = .693, +2% Δ). We found no significant changes for any of the measures ($p > .05$) for the control group. Thus, the results provide research-based evidence to support our hypothesis for all measures except the ASK-Social.

4.2. Focus group

Given the small size of the focus group, we analyzed the qualitive data in Microsoft Excel to identify and code common themes captured by the focus group notes. Before moving excerpts into an Excel file for analysis, the evaluator reviewed the notes (drafted by the original notetaker) immediately after the group to capture as much detail and context as possible from the session. We followed recommended analysis techniques for theme identification (Ryan & Bernard, 2003), which included examining text for evidence of word or phrase repetition, use of metaphors or analogies, and transitions in discussions where themes are often revealed. Results are based on prominent themes from the focus group, which may cut across multiple sections in the focus group discussion guide.

Overall, thematic analysis revealed four themes: students (1) noted the class was well organized, (2) felt the sustainability and STEM concepts flowed well together, (3) shared positive impressions of the course content, and (4) confirmed the value of the course to the university's curriculum. The students also shared that most content from *Applied Organizational Sustainability* was new to them, and

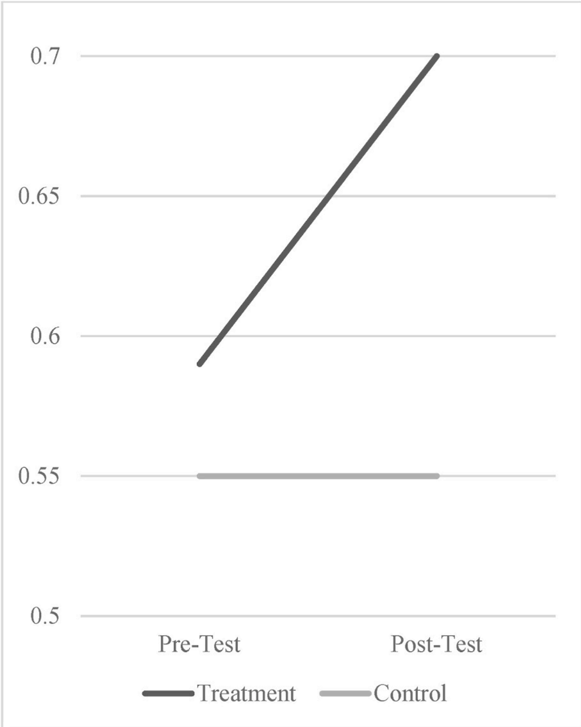

Fig. 2A. ASK.

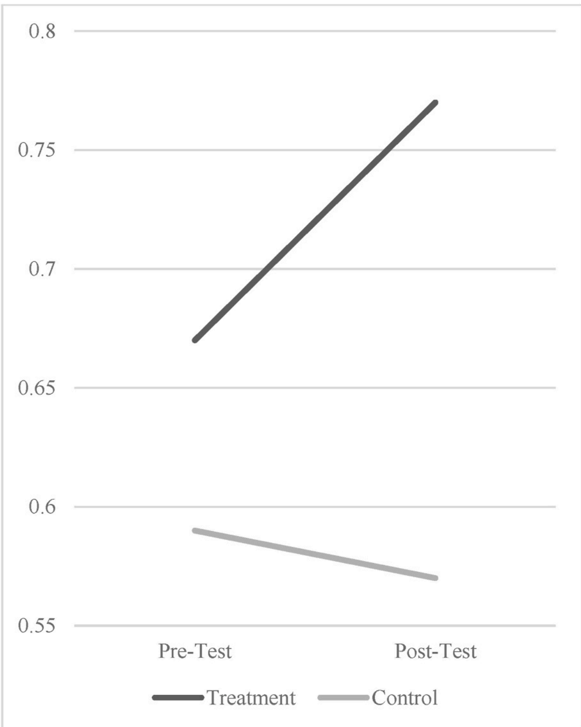

Fig. 2B. ASK–environmental.

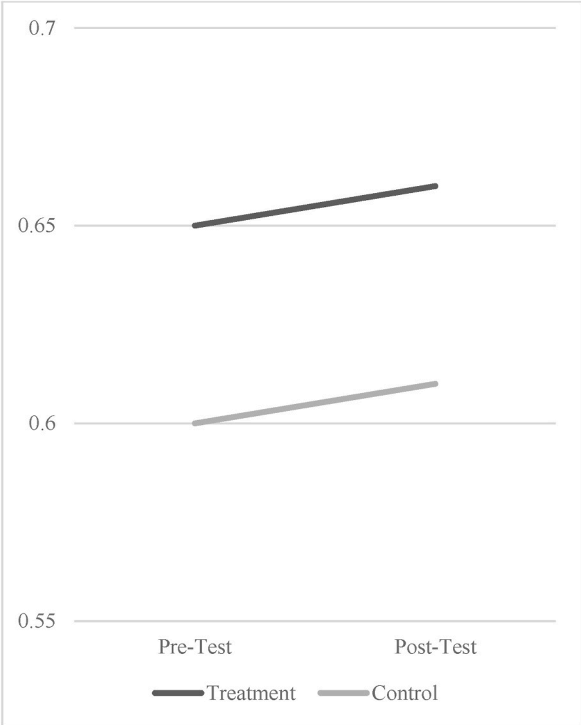

Fig. 2C. ASK-Social.
*Note. Scores did not significantly change for the treatment or control groups.

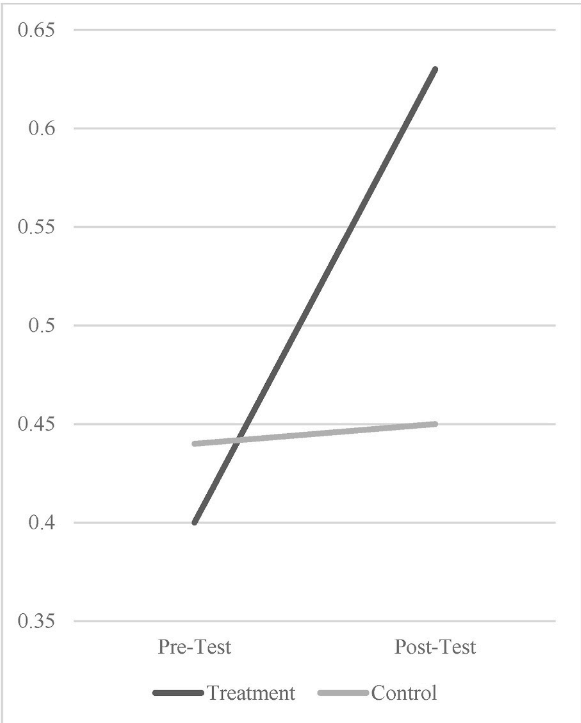

Fig. 2D. ASK-economic.

Table 6
Paired-sample correlations and t-tests.

Variable	N	R	Sig.	t	df	Sig.	SD
Treatment							
ASK	22	.62	.002	−3.08	21	.006	.16
ASK-Environmental	22	.61	.003	−2.43	21	.024	.19
ASK-Social	22	.49	.021	-.40	21	.693	.21
ASK-Economic	22	.63	.002	−4.63	21	.000	.23
Control							
ASK	29	.67	.000	.000	28	1.00	.19
ASK-Environmental	29	.48	.008	.31	28	.757	.06
ASK-Social	29	.58	.001	-.33	28	.745	.04
ASK-Economic	29	.55	.002	-.18	28	.861	.05

that the course took a more in-depth approach to environmental issues than any other course they had previously completed.

Students reported that the course was clearly linked to real-world applications, with several students noting the class was relevant to their current employment at local businesses. Further, linking weather, climate, disasters, and sustainability was appealing to students, because the enhanced understanding could be used to help their respective organizations become more prepared for related challenges. One student shared that prior to the class, they knew sustainability was generally important but did not know how to operationalize knowledge into action. At the time of the focus group, the student described several ways they implemented sustainability practices.

While the students perceived *Applied Organizational Sustainability* positively and recognized the course fills a gap in the university's curriculum, they made two key observations about areas of improvement for the course delivery. First, despite the course being asynchronous online, students expressed interest in synchronous touchpoints (e.g., check-ins via Zoom). Second, the course content is "very new" to students. They found some of the applied assignments challenging, particularly applied STEM exercises. In a formative evaluation report submitted to the sponsoring funding agency, the evaluator noted that the instructor "may need to scale back some of the content or assignments" to ensure that students can keep up throughout the semester.

5. Discussion

There are increasing calls to enhance the interdisciplinarity of sustainability in business and management education (Annan-Diab & Molinari, 2017; Bagley et al., 2020; Craig, Petrun Sayers, Gilbertz, Karam, & Feng, 2021). Highlighting a need to offer interdisciplinary STEM and sustainability curricula to business students, there are more business undergraduate degrees conferred than any other discipline: 19.5% business degrees, 12.3% health professions and related programs, 8% social sciences and history, 6.0% biological and biomedical sciences, and 5.9% psychology (National Center for Education Statistics, 2019). Smith and Watson (2019) contend sustainability education benefits from the explicit and critical application of STEM skills and understanding to sustainability-related problems. In practice, however, the enactment of interdisciplinary curriculum is difficult to accomplish due in part to instructors' (1) own disciplinary perspectives about sustainability and (2) lack of content proficiency and bandwidth to enact curricular updates (Annan-Diab & Molinari, 2017; Kurland et al., 2010).

Complex organizational and societal challenges such as climate change necessitate a STEM literate workforce from a diverse range of disciplines (Borrego & Henderson, 2014; U.S. Department of Education, 2020), including business and management graduates. Peoples' (2009) research reinforces this assertion, noting that traditional business expertise is not sufficient to make decisions in technology- or science-based organizations. In addition to meeting today's workforce needs, the exposure to STEM curriculum can also help enhance business students' earning potential. For instance, Carnevale, Cheah, and Hanson (2015) documented that on average STEM graduates earn 14% more annually in the workforce than business school graduates. Introducing *Applied Organizational Sustainability*, we provide business and management instructors/administrators with: (1) research-based evidence of interdisciplinary curriculum success from evaluation results and (2) guidance on how to adapt interdisciplinary curriculum.

5.1. Research-based evidence and strong sustainability

Using a multi-method, longitudinal evaluation design provides support for *Applied Organizational Sustainability*, its modules, its assignments, and other interdisciplinary curricula for business and management students. Our robust evaluation was designed to determine the comparative performance implications (i.e., sustainability knowledge improvement) of interdisciplinary STEM, sustainability, and management curriculum for treatment and control students. This is the first known study to identify and evaluate a stand-alone STEM and sustainability course in a business or management discipline (Petrun Sayers et al., 2020). Findings indicate that treatment students significantly improved for three of the four measures from pre-tests to post-tests (see Table 5). There were no significant changes for control students, an indication that performance improvement occurred for treatment students but not control students for each measure except for the ASK-Social.

Applied Organizational Sustainability was primarily derived from previously implemented and evaluated STEM, sustainability, and management modules from other STEM and business courses. Each of the modules, and the *Applied Organizational Sustainability* course, utilized a balanced, strong sustainability approach that did not favor any one dimension (i.e., environmental, social, economic) over another (Theis & Tomkin, 2015). For instance, the Gilbertz & Hall, 2022 case used in Module II— "The Geographic Case for Sustainability"—has a chapter dedicated to social sustainability covering topics such as water rights and environmental justice. Yet, treatment students did not significantly improve their scores on the ASK-Social on post-tests. Based on formative pilot testing (i.e., the focus group), students discussed sustainability generally and provided details pertaining to environmental and economic sustainability. The economic and environmental focus corresponds with improvement on the ASK-Environment (+11%Δ) and ASK-Economic (+23%Δ). Focus group students did not discuss social sustainability elements or outcomes (e.g., environmental justice), highlighting a curricular gap that needs to be addressed when teaching future iterations of the course.

Currently, there are assignments that address social sustainability including a small group discussion that "requires students to identify the three most dire social challenges from the [Sustainable Development Goals] and identify what United States-based businesses can do to address the challenges" (see Table 2). Students also complete two written case study assignments (i.e., Craig, 2019; Gilbertz & Hall, 2022) requiring them to respond to sustainability-challenges along each of the three dimensions of sustainability (including social). Unlike modules three and four (see Table 2), however, the experiential problem-based exercises that have social elements do not require the same level of STEM application. For instance, completing the Craig, Petrun Sayers, Feng, & Kinghorn, 2019 case requires students to interface with government technological assets (i.e., NOAA, 2021) to locate and download longitudinal meteorological data that is used to establish mathematical relationships between the natural environment and a business. Currently, there are no assignments that require students to establish mathematical relationships for social outcomes. The World Bank (2021) provides technological assets that can be utilized to assess 81 sustainable development goal indicators. An applied exercise could easily be integrated into module one that requires students to (1) locate social indicators using World Bank (2021) technological assets, (2) identify trends for countries with developed, emerging, and developing economies, and (3) establish mathematical relationships that social indicators share with economic and/or environmental indicators to inform student responses to the discussion. Previous educators have demonstrated that interconnected learning about sustainability has contributed to stronger conceptions of sustainability among students participating in curricula (e.g., Salovaara, Pietkainen, & Cantell, 2021).

Enactment of a systematic or strong approach to sustainability is difficult for organizations to accomplish, and difficult for educators to teach (Allen, 2016; Andre, 2020; Landrum & Ohsowski, 2017; Painter-Morland, Sabet, Molthan-Hill, Goworek, & Leeuw, 2016; Theis & Tomkin, 2015). For instance, Landrum and Ohsowski (2017) reviewed 81 syllabi from undergraduate sustainability courses to establish if materials used represent strong or weak conceptions of sustainability. Results demonstrate that 55% of readings advocate a weak conception of sustainability (i.e., favoring one component area over another) whereas only 29% advocate strong sustainability. As our results demonstrate, even when materials and assignments are designed and developed using a strong sustainability approach, students may not convey a completely balanced understanding of sustainability. For instance, Andre (2020) taught a *Climate Leadership* graduate course that applied theories of strong sustainability. Comparable to findings from our focus group, when completing evaluations about the course students used environmental (e.g., climate change) and economic (e.g., financial impact) terms, but there were no mentions of social constructs like human rights, environmental justice, equality, people, poverty, social, or society. Findings from Andre (2020) underscore the importance of using longitudinal, multi-method evaluation designs to ensure that the desired student outcomes are measured and ultimately accomplished. As our results demonstrate, the ASK scale (Zwickle et al., 2014; Zwickle & Jones, 2018) is a quantitative instrument that can be used alongside qualitative measures to assess if student sustainability knowledge improvement is balanced or not.

5.2. Curricular adaptation

In addition to providing research-based evidence about the positive performance implications of interdisciplinary curriculum, the study also offers guidance for how instructors/administrators can adapt or expand such curriculum. First, the *Applied Organizational Sustainability* course, its learning objectives, its modules, and its assignments can be adapted in their current form by management educators and/or programs (see Tables 1 and 2). Time and expertise are two of the primary factors prohibitive of interdisciplinary sustainability curriculum (Andre, 2020; Annan-Diab & Molinari, 2017). The time (i.e., multi-year project), resources (i.e., federally funded), and expertise (i.e., interdisciplinary team of educators) have all supported the creation of *Applied Organizational Sustainability*.

Second, the study outlines elements that instructors/administrators should consider when designing and developing interdisciplinary STEM and sustainability curriculum including (1) STEM and sustainability content requirements and (2) a shared theme and learning objective(s). These elements can help overcome some of the challenges with curriculum being perceived by students as siloed, or multidisciplinary (Kurland et al., 2010). Third, the curriculum and findings highlight the importance of the critical application of STEM for each dimension of sustainability (Smith & Watson, 2019). This is especially true for the social dimension of sustainability that was not mentioned during the qualitative evaluation and that did not improve on the quantitative evaluation.

5.3. Implications

The study highlights several key implications for instructors, administrators, students, and also the study of sustainability knowledge. For business and management instructors, the course contents and materials (e.g., learning objectives, explanation of modules) provide an entry point to teaching interdisciplinary curriculum, as well as a road map for adapting STEM and sustainability into existing management curriculum. For instance, the previously published case studies used in *Applied Organizational Sustainability* (i.e., Craig, 2019; Craig, Petrun Sayers, Feng, & Kinghorn, 2019; Gilbertz & Hall, 2022) can be adapted into existing courses, and can also serve as examples for educators interested in developing their own interdisciplinary cases. For both instructors and administrators, the results from the study provide research-based evidence to support such curricular efforts. Qualitative findings demonstrate that the content is new and novel to students, while the quantitative findings serve as an indication that engaging business students with STEM and sustainability curriculum promotes performance improvement on the ASK, the study measure of sustainability knowledge. The ASK is a useful instrument that has been used cross-sectionally to track year-to-year sustainability knowledge (Zwickle et al., 2014; Heeren et al, 2016), and as demonstrated here, can also be used to measure knowledge before and after curricular interventions.

5.4. Limitations and future research

A limitation is that *Applied Organizational Sustainability* is taught once a year online as an elective. This resulted in relatively low enrollments (n = 34), a small sample that completed pre- and post-tests (n = 22), and relatively homogeneous student demographics. However, we calculated the required sample size for paired-sample t-tests with a large effect size ($d = 0.80$), $\alpha = 0.05$, and $CI = 0.05$ for our reported changes in *sd* for each pair, finding that the pre-requisite sample size for reliable analysis to be n=20. Our sample sizes for treatment and control students exceeded this requirement. Future researchers should strive for larger sample sizes, which will also provide additional methodological flexibility.

The use of a single focus group, and the small sample size (n = 5), are also limitations, though the input students provided to the evaluator is much more robust than standard end-of-the-semester student evaluations. Another limitation is that the age of the treatment group was slightly higher than that of the control group. A possible explanation for the difference (median difference = 4.5) is that the average age of online students is higher than that for traditional in-seat bachelor students (Friedman, 2017). In each of the four treatment and control courses, there were a mix of students completely online and students who took online and in-seat courses. Future researchers should ask students about their mix of courses so that it can be included as a co-variate in analysis.

Management researchers should consider applying a comparably robust mixed-method evaluation design with treatment/control students and pre/post-tests around educational interventions among a larger and more diverse sample of students. Ideally, multiple universities could be included in such efforts, and curricular additions would be implemented in required classes with higher enrollments in addition to electives. Another limitation is that coronavirus (COVID-19) disrupted the spring 2020 semester for students and instructors. However, given that the course is delivered virtually, we believe the impact on student performance from COVID-19 in our study was mild. Student performance slightly improved on the ASK from Fall 2019 to 2020 (i.e., +4%Δ). Additional studies are needed to examine the performance effects of interdisciplinary curriculum dependent on modality due to COVID-19, including students who took part in classes that impromptu transitioned to distant education from in-person during the Spring 2020.

In practice, COVID-19 also limited curricular updates from Fall 2019 to Fall 2020. For instance, despite focus group feedback from students, synchronous touchpoints were not included in the class during the Fall 2020 term due to instructor time constraints. Synchronous touchpoints (e.g., a Zoom check-in prior to applied exercises) could potentially be used to overcome student challenges with "new" content such as the retrieval, manipulation, and statistical analysis of scientific data. Based on comments about the focus group from the evaluator, caution will be taken making curricular updates (e.g., an applied social sustainability exercise) to ensure that students can master any unfamiliar STEM or sustainability content.

6. Conclusion

To address interdisciplinary STEM and sustainability curricular deficiencies in higher education—and more precisely business and management education—we designed, developed, implemented, and evaluated a stand-alone course called *Applied Organizational Sustainability*. The course is comprised of five interdisciplinary modules, four of which were derived from previously delivered modules from STEM (e.g., *Applied Climatology)* and management courses (e.g., *Business & Environment*). Using a robust evaluation design with treatment and control groups, pre- and post-tests over multiple semesters, and mixed quantitative and qualitative measures, we demonstrate that students taking *Applied Organizational Sustainability* significantly improved sustainability literacy overall and for the environmental and economic subcategories. There were no changes in sustainability literacy or its subcategories for control students who also participated in evaluation efforts. The findings provide research-based evidence to support interdisciplinary STEM and sustainability curriculum adaptation by instructors/administrators. Furthermore, the course learning objectives (see Table 1), module descriptions, readings, and assignment descriptions (see Table 2) provide guidance for instructors/administrators interested in adapting interdisciplinary curriculum in an existing course, creating a new stand-alone interdisciplinary course, and/or integrating interdisciplinary STEM and sustainability content throughout programs.

Author statement

Craig: conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; visualization; writing-original draft; writing-review and editing; **Petrun-Sayers**: conceptualization; data curation; funding acquisition; investigation; methodology; project administration; writing-original draft; **Gilbertz**: conceptualization; funding acquisition; investigation; writing-original draft; **Karabas:** methodology; validation; writing-original draft; writing-review & editing.

Author contribution declaration

Each author participated sufficiently in the work to take public responsibility for appropriate portions of the content.

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Declaration of competing interest

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