Received 21 September 2021
Revised 9 December 2021
14 February 2022
Accepted 14 February 2022

Teaching sustainability: does style matter?

Fethiye Ozis
Department of Civil Engineering, Construction Management and Environmental Engineering, Northern Arizona University, Flagstaff, Arizona, USA

Shannon Lynn Isovitsch Parks
Department of Civil Engineering, University of Pittsburgh Johnstown, Johnstown, Pennsylvania, USA

Deborah Lynne Sills
Department of Civil and Environmental Engineering, Bucknell University, Lewisburg, Pennsylvania, USA

Mustafa Akca
Data Coordination, Covenant House Toronto, Toronto, Canada, and

Christine Kirby
Center for Health Equity Research (CHER), Northern Arizona University, Flagstaff, Arizona, USA

Abstract

Purpose – This paper aims to analyze how a tangram activity improved students' abilities to explain sustainability, articulate a positive perception of sustainable design and relate sustainability with innovation in engineering design.

Design/methodology/approach – The concept of paradigm shift was introduced in the classroom by using a tangram activity to help students understand that sustainable design requires out-of-the-box thinking. Instructors from three institutions teaching various levels of sustainability courses to engineering majors used the activity to introduce sustainable design, then measured the understanding and appreciation of the concepts introduced through the tangram activity with pre- and post-activity surveys.

Findings – Findings from the study indicate that students' perceptions of sustainability significantly improved due to the activity, without regard to the institution. The activity also significantly improved students understanding of the connection between sustainability and innovation, across all three institutions, across all majors and across all years of study except second-year students. Improving engineering students' views on sustainability may lead, over time, to changes in the industry, in which environmental performance is incorporated into the engineering design process.

Originality/value – Active learning approaches are needed for affective-domain learning objectives in the sustainability field for students to learn the necessary attitudes, values and motivations to implement

This work is supported in part by Northern Arizona University, University of Pittsburgh Johnstown, and Bucknell University.

International Journal of Sustainability in Higher Education
Vol. 23 No. 8, 2022
pp. 194-210
Emerald Publishing Limited
1467-6370
DOI 10.1108/IJSHE-09-2021-0392

sustainability in engineering design. Simple, easily implemented active learning techniques, such as the tangram activity presented here, can be implemented across the curriculum or to the public to introduce the paradigm shift necessary with sustainable design.

Keywords Sustainable development, Active learning, Paradigm shift, Sustainable design, Engineering education

Paper type Research paper

Introduction

According to the Bruntland Commission, sustainable development allows us to meet today's needs without compromising the needs of future generations (WCED, 1987). To address global environmental challenges, engineering students should be versed in sustainability and how it is incorporated into design. Understanding the concept of sustainable design is required by ABET (ABET, 2021) is included in the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers (NSPE, 2021) and is a desired technical outcome identified in the American Society of Civil Engineers (ASCE) Civil Engineering Body of Knowledge (BOK) (Bielefeldt, 2013; ASCE, 2019). The American Academy of Environmental Engineers (AAEE) Environmental Engineering BOK also includes sustainability as a skill outcome. According to AAEE, undergraduate environmental engineering graduates need to be able to explain the importance of integrating sustainability into all engineering disciplines (Bielefeldt, 2011; AAEE, 2009). As a result, civil and environmental engineering curricula have shifted over the past two decades from focusing on environmental protection to increasing focus on ethics, sustainability, natural resources, energy, cultural diversity and climate change. This was a shift to a more inter- and trans-disciplinary educational approach (Wu and Shen, 2016). However, many challenges exist to train transdisciplinary problem solvers and to create truly motivational sustainable development education (Mulder *et al.*, 2015, 2012).

Students' perceptions and understanding of sustainability may determine if they apply sustainable knowledge personally and professionally (Bielefeldt, 2013). However, engineering students often have limited understandings of sustainability. Our observations indicated that students think of recycling and reusing when it comes to sustainability, and not wider implications of integrating sustainability within the engineering design process. It is broadly accepted in practice that innovation is required to meet the challenges and opportunities presented with sustainable design (Hansen *et al.*, 2009; Schaltegger and Wagner, 2011; Rauter *et al.*, 2019), and that sustainable thinking requires a paradigm shift where education is key (Gutberlet, 2000). Active learning can be used to help students internalize broader definitions of sustainability and the paradigm shift and innovative thinking necessary to implement sustainable design in engineering practice (Dieleman and Huisingh, 2006; Maier *et al.*, 2007; Dengler, 2008). Active learning can help students understand that complex issues (e.g. sustainability) do not have simple, one-dimensional answers. Rather, solutions to these types of challenges are typically complex and multi-dimensional. Active learning applied to sustainability can promote critical thinking skills necessary for addressing issues at different spatial scales and in varied sociocultural contexts (Dengler, 2008). In these ways, active learning of sustainability concepts can target various levels of Bloom's taxonomy specifically in the affective domain which includes attitudes, values and motivations. Incorporating learning objectives from the affective domain is typically more challenging than the cognitive domain. Also, students are often unaware that they are exhibiting behaviors in the affective domain (Bielefeldt, 2013; Bloom, 1956; Anderson and Krathwohl, 2001; Krathwohl *et al.*, 1964). New active learning approaches are needed for affective-domain learning objectives in the field of sustainability.

Enhanced student learning through active engagement is not a new concept (Kolb, 1984; Kolb, 2015; Prince, 2004; Dengler, 2008; Bielefeldt, 2013; Caniglia *et al.*, 2016). The idea that experiential learning, or "learning by doing", can contribute to a student's ability to gain a deeper understanding of a concept was first explored by Kolb in 1984 (Kolb, 1984; Kolb, 2015; Ely, 2018; Dieleman and Huisingh, 2006), and is rooted in the approach developed by Tyler in 1949 (Tyler, 1949; Ely, 2018). Experiential or active learning may include a variety of activities such as role-playing, small group work, guided discussion, writing exercises (Dengler, 2008) and games (Dieleman and Huisingh, 2006). Game playing and design has also been shown to improve learning outcomes in sustainable engineering courses (Clark *et al.*, 2021). These activities provide an opportunity for personal discovery in students which enhances the learning process (Dengler, 2008; Stanley and Plaza, 2002).

However, many curricula do not incorporate active learning techniques such as games (Dieleman and Huisingh, 2006). Challenges with active learning can include absences, poorly prepared students or unexpected contributions to discussions. Limitations can also exist with large class sizes, balancing breadth and depth and fostering participation (Dengler, 2008). Therefore, simple, easily implemented active learning techniques, such as the tangram activity presented here, are especially useful. A tangram is a Chinese puzzle where various geometric shapes are recombined into different figures (Merriam-Webster, 2021), that has been used as an effective teaching tool for skills such as spatial ability (Renavitasari and Supianto, 2018; Lee *et al.*, 2009), abstract reasoning (de Carvalho *et al.*, 2019), geometry (Lin *et al.*, 2011) and collaborative learning (Valdes-Vasquez and Clevenger, 2015). Simple, yet effective, activities like the tangram can also be used to integrate sustainability across the curriculum, a requirement of engineering degrees around the world (Bielefeldt, 2013).

This paper describes how a simple hands-on tangram activity can be used to introduce the paradigm shift necessary to integrate sustainable design into traditional engineering practice. The degree to which students were better able to explain sustainability in their own words, articulate a positive perception of sustainable engineering, and relate sustainability with innovation in engineering design after the activity is measured.

Methods

Sustainability was introduced to undergraduate engineering students using tangram pieces made from colorful cardstock (Figure 1) during the first week of each of the instructors' classes at three institutions to help students understand that sustainable design requires a

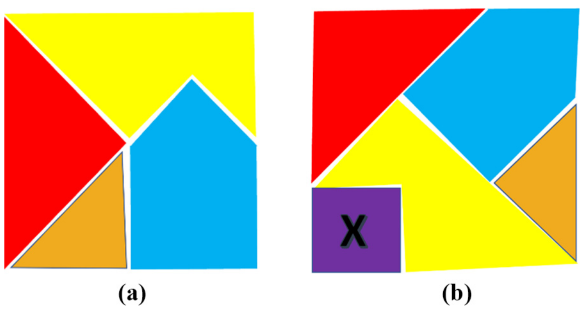

Figure 1.
(a) Initial square with four tangram pieces representing "Traditional Engineering"; (b) New square integrating sustainability (piece with "X")

paradigm shift and innovative thinking. The necessary paradigm shift was illustrated by explaining how engineering design requirements have changed to include sustainability. Student Learning Objectives of this activity included the following hitting multiple levels of Bloom's:

- explain sustainable engineering;
- compare traditional engineering to sustainable engineering; and
- relate sustainability to innovation in engineering design.

The survey asked students to define sustainability in their own words and to describe their perceptions of sustainable engineering design and how it relates to innovation. All the questions asked in the pre-survey were also asked in the post-survey. In the post-survey there were an additional nine activity related questions used to measure students' perceptions of the activity. Student respondents provided nicknames that they could remember. The responses for pre- and post-surveys were matched by using students chosen identifier (nickname). The 2019 survey collected only qualitative data; however, the 2020 survey collected both quantitative and qualitative data for a convergent parallel mixed method analysis.

To minimize biases associated with questions regarding gender and race which can draw participants' attention to stereotypes and their awareness of minorities (Chan and Luk, 2020), questions about demographic information were omitted from the survey.

The first step of the tangram activity asked students to form a square with four tangram pieces. The instructor asks students to name typical engineering constraints one at a time (analyze), then explains that each of these tangram pieces represent a constraint (resources, time, budget, etc.) (about 10 mins). Students usually spent about 5 min to figure out how to create a square with the four tangram pieces [Figure 1(a)].

Instructors explain that this square (a) represents "Traditional Engineering," i.e. in the past when we were given a problem, we solved it for the present time frame, local area or local people. In the second step, students are asked "to critique the traditional engineering design and come up with the problems associated with it" (Evaluate). The instructor guide students to realize that the dire state of the planet means that we need to adapt by designing and developing innovative technologies in a sustainable manner. Additionally, it was emphasized that engineers need to think differently (i.e. paradigm shift) – the United Nations Sustainable Development Goals require all engineers to think outside the box, and to design with global issues and future generations in mind. Environmental sustainability is one of our design requirements now. The instructor then introduces an additional tangram piece with an "X" on it [Figure 1(b)]. Students are instructed to integrate the "sustainability-piece" with the previous four pieces to create a larger square, under the assumption that the square is a design criterion of the client (create). After five minutes, students are instructed to turn to their neighbor and team up, and reminded that just like in real life, you are encouraged to work within diverse teams (collaborate). Engineers will team up with people across disciplines and industries to achieve real sustainability. At this stage, the instructor walks around to observe and provide feedback if necessary (about 25 min). At the end of the activity, the instructor explains that traditional engineering is the way we've been operating, but we need to adapt our designs for the climate change and redefine our approach to solve current problems or have a paradigm shift.

A few typically work out the solution. Afterwards, the instructor shows the solution [Figure 1(b) to whole class and collect feedback (about 10 mins)]. The tangram exercise takes place during one class period (50–75 min).

Following the IRB approval for this project (#1501545–5), the activity was performed at three institutions in the USA: Northern Arizona University (NAU), University of Pittsburgh at Johnstown (UPJ) and Bucknell University (BU). In spring 2019 at NAU, preliminary results were obtained from conducting the activity in the first-year Introduction to Environmental Engineering classroom (N = 32), where another section was used as the control group. In spring 2020, the activity was adopted for a third-year Environmental Biotechnology course (N = 19). In fall 2020, the instructor used the intervention with another first-year course Introduction to Engineering Design taught with FLEX model, where the activity was adopted for online delivery. A small group of students were online (*N* = 14) while the majority was in person (*N* = 45). At UPJ, the activity was conducted in a third-year Engineering and Sustainable Development class in the Spring of 2019 (*N* = 36) and 2020 (*N* = 30). At BU, the activity was conducted in the Spring of 2020 in a third-year Sustainability Principles for Engineers course (*N* = 59).

Analysis and results

Surveys asked seven-point Likert scale questions (1: Strongly Disagree, 2: Disagree, 3: More-or- Less Disagree, 4: Undecided, 5: More-or-Less Agree, 6: Agree, 7: Strongly Agree). There was a total of 23 survey questions (SQs), 4 of which needed reverse coding due to negative language. Research questions (*RQs*) sought to be answered were as follows:

- *RQ1*. Are students better able to explain “sustainable engineering” in their own words because of the activity?
- *RQ2*. Are students able to articulate a more positive perception of sustainable engineering design because of the activity?
- *RQ3*. Are students better able to relate sustainability with innovation in engineering design because of the activity?
- *RQ4*. What are students’ perceptions about the activity?

Both qualitative and quantitative analyses were performed. *RQ1*, articulation of sustainability, was answered based on qualitative analysis of the students’ responses provided for SQs 1 and 2. *RQ2* and *RQ3* were answered by analyzing the paired responses for pre- and post-surveys using quantitative analysis. *RQ4* was activity related; quantitative data were compiled from post-surveys only.

Data used for the qualitative analysis included both 2019 pilot data from NAU and UPJ (N = 68) and 2020 data from NAU, UPJ and BU (N = 167). These questions remained the same for both years of the study. Not all students responded to every question, resulting in a missing score on some response variables for these students. Consequently, the total sample size differed depending on the response variable analyzed. Data used for the quantitative analysis was comprised of only 2020 data from NAU, UPJ and BU.

Qualitative analysis: articulation of sustainability and sustainable engineering design

To evaluate the effect of the tangram activity on students’ abilities to explain “sustainable engineering” in their own words, the data collected from short open-ended questions (SQ1 and SQ2) from all three institutions were analyzed using ATLAS.Ti version 8 (Atlas.ti, 2021). The team approved the coding scheme (Table 1). One analyst coded the responses. Scores were given individually to each student’s response. The coding scheme was applied with a value of zero given if no elements of the correct answer was given, a value of one given if one element of the correct answer was given,

Survey question	Coding scheme	Correct elements
SQ1: In your own words, define Sustainability SQ2: Explain what engineers need to do to include sustainability in their practice	0 = No elements of the correct answer 1 = One element of the correct answer 2 = Correct answer	Meeting today's needs without compromising needs of future generations Considers the system in which the object will be used (Minimize waste, reuse or recycle materials, closed loop design; reduce environmental impact). Additionally: • Integrates technical and nontechnical issues • Strives to solve problems for the indefinite future: long term solution • Considers the global context not just local • Acknowledges need for multidisciplinary teams to approach the problem • Think outside the box

Table 1. Qualitative analysis coding scheme

and a value of two given if at least two elements of the correct answer was given. After application of the coding scheme, frequency distribution plots were created to categorize responses for SQs 1 and 2.

The following are sample excerpts from student responses for SQ1 and SQ2 from pre- and post-surveys, with their corresponding scores included in the parentheses:

> Pre-SQ1 (0): "*Used to describe something that is self-perpetuating without outside help; a repeatable process that does not compromise itself.*"

> Pre-SQ2 (0): "*to keep learning, to continue teaching others who are unaware or misinformed so that we can better communicate*".

> Post-SQ1 (1): "*providing and preparing for the future*".

> Post-SQ2 (1): "*Engineers need to think about the impact of their projects on the future instead of just worrying about present day*".

> Post-SQ1 (2): "*The method of meeting the needs of the present w/out compromising aspirations of future generations*".

> Post-SQ2 (2): "*To always try to implement the less resource-intense alternative, that meets the project scope into the project design*".

Figure 2 illustrates pre- and post-survey qualitative results for all institutions across both years. Correct answers (score of two) improved from pre- to post-survey for both questions, with a bigger improvement for *Q1* (pre-survey 18%; post-survey 52%). Likewise, completely incorrect answers (score of 0) decreased from pre- to post-survey for both questions with a 25% point drop for *Q1* and a 12% point drop for *Q2*. Results for the control data collected only in 2019 at NAU are shown as the far-left gray column. Most students who did not experience the activity either answered the question completely incorrect or only partially correct (0 or 1).

Similar results were seen when data from each school were analyzed independently (results not shown). More students answered SQ1 correctly (score of two) after the activity at all three institutions in both 2019 and 2020. More students answered SQ2 correctly after the activity at NAU in 2019 (+40%) and in 2020 (+11%) and at UPJ in 2020 (+30%). At BU in 2020, completely correct scores dropped by 4% after the activity, but slightly correct scores (score of 1) increased by 15%.

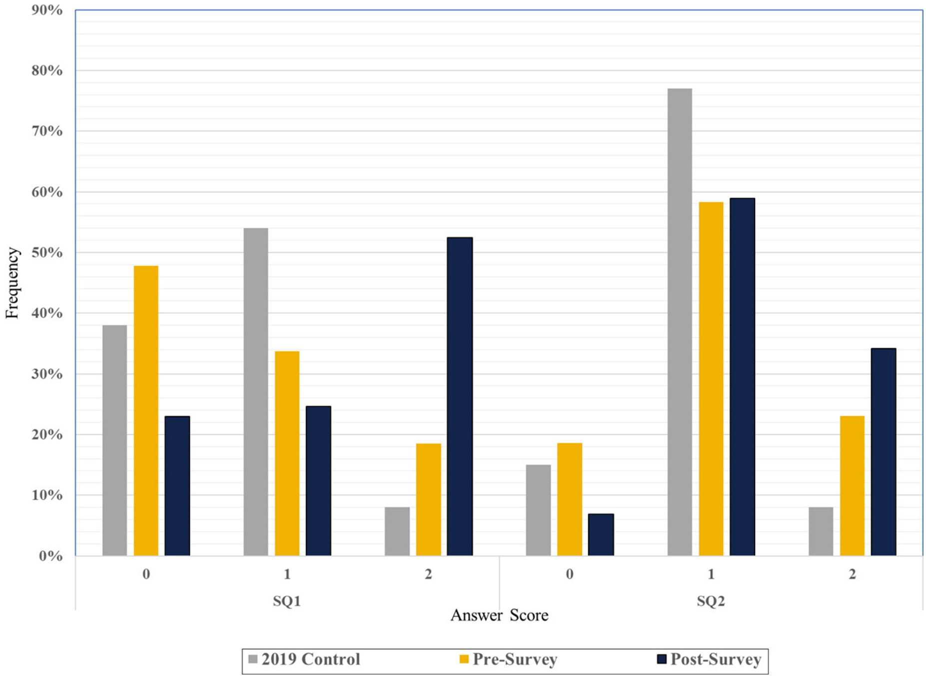

Figure 2.
Pre- and post-survey qualitative results indicating all scores for SQ1 and SQ2 for all institutions combined, 2019 and 2020

Quantitative analysis

Exploratory factor analysis was applied to mean values of the Likert scale responses for the pre- and post- answers for SQ1–SQ23, to organize the SQs into meaningful subgroups (Norris and Lecavalier, 2010). The suitability of the data for factor analysis was assessed with both the Bartlett Test and Kaiser–Mayer–Olkin (KMO) test. The strength of the relationship among SQs was assessed with Bartlett's test of sphericity (Bartlett, 1954), and the fitness of sampling was examined with KMO (Kaiser, 1970). Bartlett's test of sphericity ($\chi^2 = 553.958$, $p < 0.001$) and the KMO index (0.7999) showed that correlation matrices created from the mean values of the responses to the SQs were appropriate for factor analysis and provided validity to move forward with the factor analysis (Kaiser, 1974; Maat *et al.*, 2011).

The most appropriate number of factors to retain for the whole data set was determined by applying the Scree test (Ledesma *et al.*, 2015). The Scree plot is a graph of the reduced correlation matrix's eigenvalues plotted in descending order; the last sharp drop in values (the "elbow") represents the number of factors to be retained (Norris and Lecavalier, 2010). The eigenvalue chosen for the scree plot of this data set was associated with two factors. From the combined pre-post-survey mean responses, the two factors corresponded to *RQ2* (perception of sustainable engineering design) with the following SQs:

- SQ3: Sustainability is a key component of all engineering disciplines.
- SQ4: As an engineer, it is important to implement sustainability in my design.
- SQ10: Sustainable Development is a good thing.

- SQ12: I am open to changes in traditional ways of practicing even if it requires effort and work.
- SQ13: I am a passionate advocate of sustainability.

and *RQ3* (relating sustainability to innovation) with the following SQs:

- SQ7: Sustainable design requires out-of-the-box thinking.
- SQ8: Sustainable design means innovation.
- SQ9: To implement sustainability, one needs to be innovative.

An additional factor emerged when only post-surveys considered, factor 3 (Activity), which included all nine activity related questions as follows:

- SQ15: This activity improved my understanding of the sustainable engineering design.
- SQ16: This activity was useful in promoting my learning about sustainable engineering design.
- SQ17: This activity helped me understand the nuances between traditional engineering and sustainable engineering design.
- SQ18: What I learned in this activity is important for me as a future engineer.
- SQ19: This activity to teach Sustainable engineering design was interesting and engaging.
- SQ20: This activity motivated me to learn more about sustainable engineering design.
- SQ21: This activity was a waste of time.
- SQ22: I benefited from this tangram piece learning activity.
- SQ23: If my definition of sustainability changed, I can attribute some or all of that change to this activity (question is adapted from Bramald and Wilkinson, 2009).

Though "paradigm shift" is not explicit in the SQs, it is inferred in SQ12 and SQ17, as they highlight the change needed from traditional to sustainable engineering design.

Then inferential statistical analyses, including paired t-tests and ANOVA, were used to determine if there is a significant difference between the means of the groups. All statistical analyses, t-tests, ANOVA, factor analysis, including Bartlett test, KMO and factor selection were performed in Python (version 3.6.5).

Initial grouping was done by considering the course delivery method: online or in-person. The data analysis showed no statistical difference between the online (N = 14) and in-person (N = 153) students for either factor [Factor 1 (Perception) $p = 0.942$(pre) and $p = 0.386$(post) and Factor 2 (Innovation) $p = 0.596$(pre) and $p = 0.166$(post)], therefore the data are all combined in the whole group analysis.

Analysis that compared pre- and post-activity SQs was performed for the whole group (three institutions combined), then for each institution. Additionally, cross-case analysis was used to look for patterns across variables within the data including major and year of study for respondents. One way ANOVA tests across institutions were performed to determine if the activity affected Perception. ANOVA revealed p-values of 0.390 (pre) and 0.761(post) for Factor 1 (Perception), 0.257 (pre) and 0.378 (post) for Factor 2 (Innovation) and 0.040 (post only) for Factor 3 (Activity). Therefore, the null hypothesis stating that "the population means are all equal" was rejected for Factor 3 only ($p < 0.05$).

Perception of sustainable engineering design

To answer *RQ2*: "Are students able to articulate a more positive perception of sustainable engineering design because of the activity?" We looked at Factor 1 (Perception) and corresponding SQs' responses. The whole group (N = 167) data analysis for Perception (Factor 1) resulted in a mean of 6.027 for pre- and 6.269 for post-surveys, with a standard deviation of 0.820 for pre- and 0.789 for post-surveys as seen in Figure 3. Cronbach's alpha values for both pre- and post-surveys were calculated to be 0.804, 0.849 for Perception, confirming the internal measure of consistency. Additionally, Tukey's post-hoc method was used to compare the mean values for the Likert scale (0–7) of all possible pairs (pre- and post-activity) of all groups. For each of the factors, an improvement was indicated by a higher mean score in the post-survey.

Figure 3 shows the mean and standard deviation of pre- and post-surveys for the whole group and for each school (NAU, BU and UPJ) for Perception of Sustainable Engineering Design (Factor 1). Between each set of means and standard deviations are the *t*-test results of the mean response comparisons.

Figure 3 also shows the mean and standard deviation of Perception (Factor 1) for pre- and post-surveys with respective N values and *t*-test results. When *t*-test was applied to all data, the results revealed that there is a statistically significant increase for perception of sustainability from pre-mean to post-mean (p = 1.216E-08). T-test between pre- and post-surveys for individual schools shown on horizontal arrows indicate that there are statistically significant differences between pre- and post-survey responses for every individual school with all values of $p < 0.05$. All paired comparisons of pre- and post-surveys, between NAU and BU, BU and UPJ and UPJ and NAU (vertical and curved arrows) were found not to be significant, for data analyzed for Perception.

Sustainability and innovation

To answer *RQ3*: "Are students better able to relate sustainability with innovation in engineering design because of the activity?" We looked at Factor 2 (Innovation) and corresponding SQs' responses. Cronbach's alpha values for both pre- and post-surveys were calculated to be 0.748, 0.849 for innovation, showing high internal consistency.

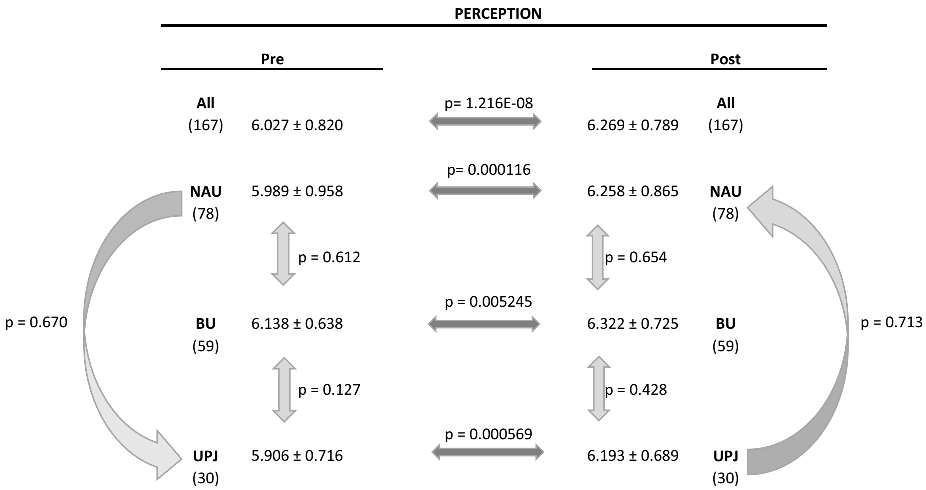

Figure 3.
Summary statistics for whole group and individual schools for Factor 1 (Perception)

Figure 4 displays the mean and standard deviation of Innovation (Factor 2) for pre- and post-surveys, with respective N values and t-test results for each school. Between each set of means and standard deviations, are the t-test results of those comparisons. The whole group data analysis for *Relating Sustainability to Innovation* showed that there was a statistically significant increase from pre-mean response to post-mean response (p = 2.56E-15), indicating students showed a higher level of relation between sustainability and innovation after the activity.

T-test between pre- and post-surveys for individual schools shown on horizontal arrows indicate there is a statistically significant difference between pre- and post-survey responses for every individual school with all values of $p < 0.05$. Again, the paired comparisons between institutions were found not to be significant, for both pre- and post-surveys, when data were analyzed for Innovation. All values of p (vertical and curved arrows) were greater than 0.05. There were no significant differences identified between institutions. The specific instructional activity-described above was delivered uniformly across all three intuitions.

By major. Environmental, Civil and Other Engineering majors included of 27.5%, 41.3%, and 31.2% of the whole group. One way ANOVA test discovered p values for pre- and post-surveys among the three groups as follows, for Factor 1 (Perception): 0.980 (pre) and 0.669 (post), and for Factor 2 (Innovation) 0.996 (pre) and 1.000 (post). All p values for ANOVA were greater than the significance level of 0.05, providing not enough evidence to reject the null hypothesis of having all means equal. Next, Tukey's *post-hoc* method was used. Pre-and-post-survey means, standard deviations and t-test values for both factors of Perception and Innovation separated by major were analyzed (results not shown). The results indicate that environmental engineering students had a relatively higher initial Perception (6.343 ± 1.047). Civil engineering students reported the lowest pre-mean (5.896 ± 1.110) for Perception. Post survey means revealed that civil and environmental engineering perception gap was closed after the activity (mean 6.249). Both civil and environmental engineering majors presented a higher positive Perception as compared to other engineering majors. The t-test analysis showed that the increase from pre-to post mean perception for civil engineering major students was significant (p = 0.009).

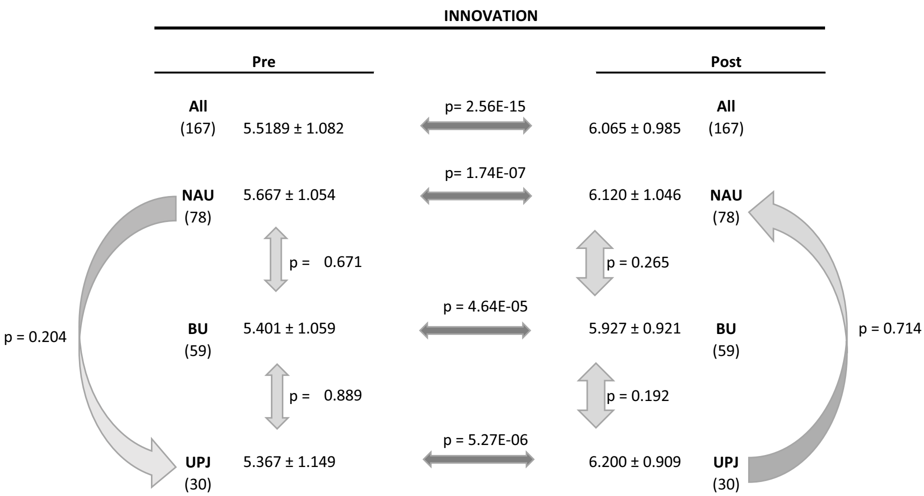

Figure 4. Summary statistics for whole group and individual schools for Factor 2 (Innovation)

The pre-survey means showed again environmental engineering students related sustainability with Innovation higher than their peers. It is notable that after the activity all majors reported almost the same level of agreement for Innovation and Sustainability. T-test results indicated that all majors had a significant positive improvement for Factor 2, relating sustainability with innovation from pre- to- post-survey.

By year of study. The whole group was comprised of 63 (37.7%) First-year, 37(22%) Second-year, 45(27%) Third year and 22(13%) Fourth-year students. One way ANOVA test identified p-values for pre- and post-surveys among the three groups as follows for Factor 1 (Perception): 0.138 (pre) and 0.690 (post), and for Factor 2 (Innovation) 0.655 (pre) and 0.313 (post). All p-values for ANOVA were greater than the significance level of 0.05, providing insufficient evidence to reject the null hypothesis of all means being equal. However, multiple comparison was achieved again by using Tukey's post-hoc method. Pre- and post-survey means, standard deviations and t-test values for both Factors of Perception and Innovation separated by year of study were analyzed (results not shown). The pre-survey mean perception among first-year students was 5.975 ± 1.083 (More or Less Agree). After a slight dip for second-year students (5.816 ± 1.081), it increased for third-year and fourth-year students, reaching 6.227 ± 1.080 (Agree). Post-survey mean perception was highest for third-year students. T-test results comparing pre- to post-activity perception by year of study revealed no significant difference for any of the groups.

Pre-survey mean innovation scores showed that first-year students related sustainability with innovation higher (5.656 ± 1.077) than other groups before the activity. Post mean innovation scores showed a significant increase for all groups except second-year students (p-value 0.090). Second-year group post mean was 5.838 ± 1.055 falling within the More or Less Agree category, while other groups post-survey means were all above 6 falling within the Agree category.

Perception about the activity. To answer *RQ4*: "What are students' perceptions about the activity?", we analyzed Factor 3: Activity Related SQs and responses. There were nine questions corresponding to the activity and its value. The same seven-point Likert-scale was applied to all questions pertaining activity. There was one negatively worded question "This activity was a waste of time", which was reversely coded to align with the rest of the group. Cronbach's alpha, an important variable for confirmatory factor analysis, for all nine questions revealed high internal consistency (Cronbach's alpha > 0.900 for all institutions). The average of mean scores for all nine questions fall between "More or Less Agree (5) to Agree (6)". One way ANOVA comparison of the means between three institutions revealed $p = 0.04$, and the null hypothesis of having all means equal was rejected.

To analyze every possible combination, Tukey's post hoc (t-test) was employed, indicating that UPJ students' perception about the activity (5.956 ± 0.849) is slightly but not statistically significantly higher than NAU students (5.808 ± 0.901; $p = 0.444$). However, there were statistically significant difference between NAU and BU (5.490 ± 0.919; $p = 0.046$) and BU and UPJ ($p = 0.024$) pairs.

Discussion

In 2019, the tangram activity was piloted with N = 68 students, who completed pre- and post-surveys. A control group with N = 26 completed pre- and post-surveys without the activity. After participating in the tangram activity, students improved their abilities to define sustainability in their own words. Students not only realized that there are challenges associated with sustainability, but they also connected sustainability with innovation and the activity improved their understanding of sustainable engineering design (Ozis *et al.*, 2019).

Finally, students agreed that participating in this activity was an interesting and engaging way to learn about sustainability.

In 2020, N = 167 students were introduced to the Sustainable Engineering Design concept with the tangram activity across three institutions. Mixed method convergent parallel design was employed by performing both qualitative and quantitative analyses. The qualitative analysis included data from 2019 and 2020 and indicated that the activity improved students' ability to correctly define sustainability in their own words (SQ1) and explain what engineers need to do to implement sustainability (SQ2). A more consistent improvement was seen in SQ1 compared to SQ2, which was looking for students to identify the need to reduce environmental impact in engineering projects.

For the quantitative results, although there were no statistically significant differences among institutions, there were significant differences between pre- and post- means responses (based on a Likert scale) for every factor at each institution. Similarly, qualitative analysis of SQ1 showed improvement across all institutions both in 2019 and in 2020. This suggests that the activity can be effectively replicated at various institutions with various instructors.

As part of the quantitative analysis, exploratory factor analysis revealed two factors that were important for consideration: Perception and Innovation. A third factor from the post-survey was identified as Activity. Results show a significant increase from pre-to-post for student Perception of sustainability, collectively as a whole group as well as for individual institutions. Civil engineering students improved their perception significantly as compared to their counterparts in Environmental engineering and other engineering. This could be because environmental engineering students began with a strong perception of sustainability (Pre-mean of 6.343). Even the "Other" category began with a higher mean (5.923) for the Perception factor compared to civil engineering majors (5.896), though not significantly different. In the post-survey data, civil engineering majors improved their perception of sustainability to meet that of the environmental engineering majors (both post-survey means 6.249). Students from other engineering majors showed improvement (post-survey mean 6.135) but not to the same extent. Stratified data revealed no statistical significance between pre- and-post for Perception by the year of study, although upper-level students scored higher in the pre- and post-surveys than lower-level students.

Quantitative results also indicated a significant increase for students' ability to relate sustainability with Innovation, which indirectly refers to a paradigm shift necessary in practice. All majors improved significantly on the Innovation factor, and related sustainability with Innovation more because of the activity. All years of study except second-year students had a significant improvement for relating sustainability with innovation. Notably, first-year students had the highest mean (pre-survey 5.656) in the pre-survey for Innovation. Introducing sustainable engineering design with such an activity early in the curriculum could benefit students by helping them to keep a positive attitude toward sustainability. Fourth-year students showed the most significant improvement in relating sustainability with Innovation, with a pre-survey mean of 5.455 and the highest post-survey mean of all the years of 6.318 (p-value 0.006).

Overall student perception of the activity was positive indicating that the activity was useful promoting learning about sustainable engineering design. The significant improvement in students' perception and ability to relate sustainability to innovation indicate an appreciation for the need for "thinking outside the box", or a paradigm shift, to implement sustainable engineering. The activity was perceived as motivational for students to learn more about sustainable engineering design. One limitation of this work is that a motivation to learn about sustainable engineering design will not necessarily translate to changes in industry or have a beneficial impact on society. However, if students are motivated to learn about sustainability as part of the engineering design process, this could potentially (over time) translate to changes in the industry. Future research with practicing engineers could be conducted to evaluate the effect of the tangram exercise presented here as part of continuing education programs in the industry.

Conclusion

The global climate crisis necessitates innovative pedagogy that nurtures "thinking outside the box." Such pedagogy should actively engage students in a paradigm shift that will integrate sustainable design into traditional engineering practice to provide innovative engineering solutions. Teaching sustainable design using a tangram activity was evaluated in engineering courses at three universities with the hypothesis that teaching sustainability with the tangram activity presented here would lead to more positive perception about sustainable engineering design among students, who may relate sustainability with innovation and thinking outside the box. The goal was to teach them that sustainable engineering design is doable but requires innovation. To evaluate the effect of the tangram activity, student surveys asking both open ended and Likert scale questions were used to measure perceptions and beliefs before and after the activity, by using both qualitative and quantitative analyses.

Overall, the simple tangram activity was found to be effective in improving students' ability to define sustainability, explain what engineers need to do to implement sustainable practices and improve students' perceptions of sustainability and its connection to innovation. The activity significantly improved students understanding of the connection between sustainability and innovation, across all three institutions, across all majors and across all years of study except second-year students. Furthermore, the students enjoyed it! Findings from the study indicated that students' perceptions of sustainability improved significantly due to the activity, without regard to the instructor or institution. This indicates the simple tangram activity can be applied at various institutions to effectively introduce sustainability concepts. The activity can be effective for various majors and bring non-environmental engineering majors to have a similar perception of sustainability as those students choosing this field as their major.

Because the activity is simple, can be completed in one class period and has been shown to be effective for a variety of students, it may also serve well in industry, in primary education, or even with the public. As we move to bring sustainability to the forefront, it is vital to share its importance and connection to innovation across disciplines, in practice, and to the public. This activity could be a start to doing this.

Limitations

There are several limitations in this study. First, the total number of participants in the study was not large. Future research could include a larger sample. While this study did have a small variety of majors, it focused on engineering students. Future work could include extension of the activity in industry, the public and primary education. Another limitation is due to students' self-rated responses, which might have caused a ceiling effect, and impacted significance of some parameters measured in the pre-survey. For instance, environmental engineering majors most likely have a higher interest and motivation about sustainability, thus creating limited statistical variance between pre and post responses. Further, there is a limitation related to the perception of the activity as the only factor for the change in students' definition of sustainability. In addition, this study lacks the data analysis to see what percentage of students with a score of 2 came from 0, 1 or maintained 2 pre to post. Finally, motivation to learn about sustainable engineering design will not necessarily translate to changes in industry or have a beneficial impact on society. However, if students are motivated to learn about sustainability as part of the engineering design process, this could potentially (over time) translate to changes in industry. Future research with practicing engineers could be conducted to evaluate the effect of the tangram exercise presented here as part of continuing education programs in industry.

References

AAEE (2009), “Environmental engineering body of knowledge”, American Academy of Environmental Engineers, The Environmental Engineering Body of Knowledge Task Force.

ABET (2021), “Criteria for accrediting engineering programs, 2021-2022”, available at: www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2021-2022/

Anderson, L.W. and Krathwohl, D.R. (Eds) (2001), *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, Longman, New York, NY.

ASCE (2019), *Civil Engineering Body of Knowledge: Preparing the Future Civil Engineering*, 3rd ed., Reston: American Society of Civil Engineers, Civil Engineering Body of Knowledge 3 Task Committee.

Atlas.ti (2021), “Atlas.ti: the qualitative data analysis and research software”, available at: https://atlasti.com/ (accessed 9 August 2021).

Bartlett, M.S. (1954), “A note on the multiplying factors for various χ 2 approximations”, *Journal of the Royal Statistical Society: Series B (Methodological)*, Vol. 16 No. 2, pp. 296-298.

Bielefeldt, A. (2011), “Incorporating a sustainability module into first-year courses for civil and environmental engineering students”, *Journal of Professional Issues in Engineering Education and Practice*, Vol. 137 No. 2, pp. 78-85.

Bielefeldt, A.R. (2013), “Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students”, *Sustainability*, Vol. 5 No. 10, pp. 4479-4501.

Bloom, B.S. (Ed.) (1956), *Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook 1: Cognitive Domain*, David McKay, New York, NY.

Bramald, T. and Wilkinson, S. (2009), “Introducing and stimulating sustainable engineering in first year civil engineering students”, *Proceedings of the 2009 American Society for Engineering Education Annual Conference and Exposition*.

Caniglia, G., John, B., Kohler, M., Bellina, L., Wiek, A., Rojas, C., Laubichler, M.D. and Lang, D. (2016), “An experience-based learning framework: activities for the initial development of sustainability competencies”, *International Journal of Sustainability in Higher Education*, Vol. 17 No. 6, pp. 827-852, doi: 10.1108/IJSHE-04-2015-0065.

Chan, C.K. and Luk, L.Y. (2020), “Development and validation of an instrument measuring undergraduate students' perceived holistic competencies”, *Assessment and Evaluation in Higher Education*, Vol. 46 No. 2, pp. 1-16.

Clark, R., Spisso, A., Ketchman, K.J., Parrish, A.E., Landis, K., Mohammadiziazi, R. and Bilec, M.M. (2021), “Gamifying sustainable engineering courses: student and instructor perspectives of community, engagement, learning, and retention”, *Journal of Civil Engineering Education*, Vol. 147 No. 4, p. 4021009.

de Carvalho, C.V., Bessa, P., Costa, R., Barata, A. and Costa, A. (2019), “LearnIt: a serious game to support study methods in engineering education”, *2019 IEEE Global Engineering Education Conference (EDUCON)*, IEEE, pp. 959-967.

Dengler, M. (2008), “Classroom active learning complemented by an online discussion forum to teach sustainability”, *Journal of Geography in Higher Education*, Vol. 32 No. 3, pp. 481-494.

Dieleman, H. and Huisingh, D. (2006), "Games by which to learn and teach about sustainable development: exploring the relevance of games and experiential learning for sustainability", *Journal of Cleaner Production*, Vol. 14 Nos 9/11, pp. 837-847.

Ely, A.V. (2018), "Experiential learning in 'innovation for sustainability': an evaluation of teaching and learning activities (TLAs) in an international masters course", *International Journal of Sustainability in Higher Education*, Vol. 19 No. 7, pp. 1204-1219, doi: 10.1108/IJSHE-08-2017-0141.

Gutberlet, J. (2000), "Sustainability: a new paradigm for industrial production", *International Journal of Sustainability in Higher Education*, Vol. 1 No. 3, pp. 225-236.

Hansen, E.G., Grosse-Dunker, F. and Reichwald, R. (2009), "Sustainability innovation cube – a framework to evaluate sustainability-oriented innovations", *International Journal of Innovation Management*, Vol. 13 No. 4, pp. 683-713.

Kaiser, H.F. (1970), "A second generation little jiffy", *Psychometrika*, Vol. 35 No. 4, pp. 401-415.

Kaiser, H.F. (1974), "An index of factorial simplicity", *Psychometrika*, Vol. 39 No. 1, pp. 31-36.

Kolb, D.A. (1984), *Experiential Learning: Experience as the Source of Learning and Development*, Prentice-Hall, Englewood Cliffs, NJ.

Kolb, D.A. (2015), *Experiential Learning: Experience as the Source of Learning and Development*, 2nd ed., Pearson Education, Upper Saddle River, NJ.

Krathwohl, D.R., Bloom, B.S. and Masia, B.S. (1964), *Taxonomy of Educational Objectives, Handbook II: Affective Domain*, David McKay, New York, NY.

Ledesma, R., Valero-Mora, P. and Macbeth, G. (2015), "The scree test and the number of factors: a dynamic graphics approach", *The Spanish Journal of Psychology*, Vol. 18, pp. E11-E11.

Lee, J., Lee, J.O. and Collins, D. (2009), "Enhancing children's spatial sense using tangrams", *Childhood Education*, Vol. 86 No. 2, pp. 92-94.

Lin, C.-P., Shao, Y.-J., Wong, L.-H., Li, Y.-J. and Niramitranon, J. (2011), "The impact of using synchronous collaborative virtual tangram in children's geometric", *Turkish Online Journal of Educational Technology – TOJET*, Vol. 10 No. 2, pp. 250-258.

Maat, S.M., Zakaria, E., Nordin, N.M. and Meerah, T.S.M. (2011), "Confirmatory factor analysis of the mathematics teachers' teaching practices instrument", *World Applied Sciences Journal*, Vol. 12 No. 11, pp. 2092-2096.

Maier, H.R., Baron, J. and McLaughlan, R.G. (2007), "Using online roleplay simulations for teaching sustainability principles to engineering students", *International Journal of Engineering Education*, Vol. 23 No. 6, pp. 1162-1171.

Merriam-Webster. (2021), "Tangram", available at: www.merriam-webster.com/dictionary/tangram (accessed 16 November 2021).

Mulder, K.F., Segalas, J. and Ferrer-Balas, D. (2012), "How to educate engineers for/in sustainable development", *International Journal of Sustainability in Higher Education*, Vol. 13 No. 3, pp. 211-218.

Mulder, K.F., Ferrer, D., Segalas Coral, J., Kordas, O., Nikiforovich, E. and Pereverza, K. (2015), "Motivating students and lecturers for education in sustainable development", *International Journal of Sustainability in Higher Education*, Vol. 16 No. 3, pp. 385-401.

Norris, M. and Lecavalier, L. (2010), "Evaluating the use of exploratory factor analysis in developmental disability psychological research", *Journal of Autism and Developmental Disorders*, Vol. 40 No. 1, pp. 8-20.

NSPE (2021), "NSPE code of ethics for engineers", available at: www.nspe.org/resources/ethics/code-ethics (accessed 17 June 2021).

Ozis, F., Parks, S.L.I. and Kirby, C. (2019), "Teaching sustainability: does style matter?", *Association of Environmental Engineering and Science Professors (AEESP) Conference Presentation*.

Prince, M. (2004), "Does active learning work? A review of the research", *Journal of Engineering Education*, Vol. 93 No. 3, pp. 223-231.

Rauter, R., Globocnik, D., Perl-Vorbach, E. and Baumgartner, R.J. (2019), "Open innovation and its effects on econcomic and sustainability innovation performance", *Journal of Innovation and Knowledge*, Vol. 4 No. 4, pp. 226-233.

Renavitasari, I.R.D. and Supianto, A.A. (2018), "Educational game for training spatial ability using tangram puzzle", *2018 International Conference on Sustainable Information Engineering and Technology (SIET)*, IEEE.

Schaltegger, S. and Wagner, M. (2011), "Sustainable entrepreneurship and sustainability innovation: categories and interactions", *Business Strategy and the Environment*, Vol. 20 No. 4, pp. 222-237.

Stanley, K. and Plaza, D. (2002), "No passport required: an action learning approach to teaching about globalization", *Teaching Sociology*, Vol. 30 No. 1, pp. 89-99.

Tyler, R.W. (1949), *Basic Principles of Curriculum and Instruction*, University of Chicago press.

Valdes-Vasquez, R. and Clevenger, C.M. (2015), "Piloting collaborative learning activities in a sustainable construction class", *International Journal of Construction Education and Research*, Vol. 11 No. 2.

WCED (1987), "Report of the world commission on environment and development: our common future", UN Documents: Gathering a Body of Global Agreements.

Wu, Y.-C.J. and Shen, J.-P. (2016), "Higher education for sustainable development: a systematic review", *International Journal of Sustainability in Higher Education*, Vol. 17 No. 5, pp. 633-651.

About the authors

Fethiye Ozis is a senior lecturer in the civil and environmental engineering department at Northern Arizona University (NAU). Dr Ozis holds a B.S. in environmental engineering from the Middle East Technical University, Ankara, Turkey and MS and PhD degrees from the University of Southern California. Dr Ozis is a licensed Professional Engineer, Environmental, in Arizona. Dr Ozis enjoys every dimension of being an engineering educator. She teaches across the curriculum from freshman introductory level to fundamental environmental engineering courses, and elective courses in air quality and biotechnology. Dr Ozis conducts research related to engineering classrooms and innovative pedagogical strategies. She has been an ASCE Excellence in Civil Engineering Education fellow since 2016, and currently serves as an assistant mentor. Dr Ozis has earned multiple teaching, research, and service awards, culminating in the "Teacher of the Year" award from the College of Engineering, Informatics and Applied Sciences at NAU in 2020. Fethiye Ozis is the corresponding author and can be contacted at: fozis@andrew.cmu.edu

Shannon Lynn Isovitsch Park is a registered Professional Engineer with 20+ years of broad-based experience in the water resources and environmental engineering fields. She holds a Bachelor of Science Degree in Civil Engineering from the Pennsylvania State University and a Master of Science and doctoral degree in Civil and Environmental Engineering from Carnegie Mellon University. She has been teaching water resources and environmental engineering at UPJ since 2016. Prior to joining UPJ, Dr Parks worked for over seven years at the Alcoa Technical Center focusing on development and commercialization of sustainable wastewater treatment and solid waste reuse technologies. She also served as a member of the Alcoa Foundation Board of Directors, providing environmental expertise to support the Foundation's focus areas of Environment, Empowerment and Education, as well as her experience with science, technology, engineering and mathematics education for women. Prior to joining Alcoa, Dr Parks worked for approximately seven years as a consultant to government agencies, municipalities, and industrial clients performing water resources engineering design and permitting. In addition to her corporate experience, Dr Parks served as a Peace Corps Volunteer in Mali, West Africa, supporting a local Non-Governmental Organization on water sanitation projects.

Deborah Lynne Sills is an Associate Professor in the Department of Civil and Environmental Engineering at Bucknell University. Her teaching focuses on traditional environmental engineering, sustainability, and engineering justice. Her research focuses on sustainable resource recovery from

biomass – such as wastewater, animal manure and microalgae. Dr Sills conducts laboratory studies, in addition to modeling studies that use life cycle assessment and technoeconomic analysis to evaluate environmental and economic performance of resource recovery technologies. She received her PhD in environmental engineering from Cornell University, and a BS in civil engineering from Montana State, Bozeman.

Mustafa Akca is a Canada-based Data Engineer. He holds a BS in Industrial Engineering from Sakarya University, Turkey and MS in Engineering Mathematics at Yildiz Technical University, Istanbul, Turkey. He has experience of 10+ years in the industry. Akça is an expert on Microsoft Excel, he has published two books on MS Excel and data analytics.

Christine Kirby (MA) is a senior researcher coordinator at Northern Arizona University with the Center for Health Equity Research. She holds a BS in multidisciplinary anthropology from the Appalachian State University and MA in linguistic anthropology from the Northern Arizona University. Currently, Christine is pursuing PhD in Interdisciplinary health at NAU. She has a background in conversation analysis, doctor/patient communication, and qualitative research design. Her training is rooted in qualitative and quantitative research with a focus on Jefferson notation transcription, conversation analysis, discourse analysis, and qualitative coding. Christine has contributed to multiple health equity research teams including medical communication research at Duke University and HIV and community-based participatory research at The University of North Carolina at Chapel Hill.