ENTREPRENEURIALLY MINDED LEARNING IN THE UNIT OPERATIONS LABORATORY THROUGH COMMUNITY ENGAGEMENT IN A BLENDED TEACHING ENVIRONMENT

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INTRODUCTION

The COVID-19 pandemic generated a need for implementing many untested remote learning opportunities in the chemical engineering curriculum. Significant changes to the learning environment emerged, including reduced interpersonal interactions due to social distancing and fewer in-person learning opportunities due to academic calendar modifications. This resulted in online learning implementation at the start, end, or throughout entire semesters. These transitions have been particularly challenging to address within traditional chemical engineering Unit Operations Laboratory courses that rely on hands-on interactions with experimental equipment.[1–3] In our study, we note that such barriers to conventional face-to-face and hands-on laboratory work impacted student motivation and creative problem-solving skills, making the situation much more challenging for those who are not highly self-directed learners.

In addition to the hands-on experiences offered in a laboratory, distance learning also impacts developing practical skills related to teamwork, safety, technical data review, and presentations, as well as applying core chemical engineering concepts learned in classroom settings. With this need for new pedagogical methods, an opportunity to provide practical and measurable educational value became available for many universities worldwide. For example, online laboratories have integrated activities such as performing home-lab experiments, using computational tools, visualizing experiments, or researching question-driven problems.[4,5]

In addition to the impact of COVID-19, there are additional challenges to the effective teaching of chemical engineering laboratory courses. A recent study highlighted that traditional laboratory settings primarily provide recipe-style activities that undermine critical thinking and real-life scenarios.[6] On the contrary, open-ended approaches to problem-solving for a community partner provides a rich context for self-directed learning, relying heavily on critical thinking and applied knowledge.[7,8] To our knowledge, few studies in chemical engineering undergraduate laboratories have used community-based learning, such as incorporating outreach presentations to the community[9] or applying Kolb's experiential learning cycle in a process control laboratory.[10]

In this study we take advantage of the unique prevalence of remote online learning during a semester of blended learning by fostering a more "open-ended" approach towards delivering chemical engineering unit operations through a final project-based activity with an actual community partner. With this approach and a focus on creating societal value for an authentic external stakeholder, we incorporated key elements of the KEEN (Kern Entrepreneurial Engineering Network) entrepreneurially minded learning (EML) framework. We generated opportunities for students to be self-directed learners. To measure the extent to which the students were prepared for self-directed learning, we used the self-directed learning readiness scale (SDLRS).[11,12] This scale measures an individual's perception of their attitude and skills necessary for learning in more open-ended and inquiry-based environments, including the perceived value of and demonstrated curiosity towards learning new material and approaching open-ended problems as challenges rather than obstacles.[13] To the authors' knowledge, EML and self-directed learning have not been assessed or implemented in a chemical engineering Unit Operations Laboratory, either in traditional laboratory settings or during the disruptive distance learning caused by the pandemic.

BACKGROUND

Unit Operations Laboratory: Blended Learning

Due to the pandemic, the University of Dayton changed Fall 2020's semester schedule by including online learning in addition to face-to-face learning. After the traditional Thanksgiving break, students moved to an online-only learning modality for the last three weeks of the semester. This combined learning methodology is known as blended learning, which is challenging and requires pedagogical changes and connecting technology to learning processes.[14] Unexpectedly, the semester also began with three weeks of online-only learning due to rising COVID-19 cases on campus. Thus, the Unit Operations Laboratory course met in person for only ~ 8 weeks (modified for social distancing). The blended learning format presented a significant challenge but also provided the opportunity to explore novel online learning options for the last few weeks of the Unit Operations Laboratory course. Under typical conditions, the final month of the semester is devoted to a final project where students extend an experiment study beyond the routine tasks of formulating an objective, operating the apparatus, recording data, and reporting results as documented previously.[2] Examples of final project assignments include exploring the impact of design modifications on existing systems, such as retrofitting a multi-tray distillation column; operating with more challenging materials, such as using shear-thickening fluids in agitation; or unit optimization, such as maximizing spray dryer powder recovery. The challenge for this semester was to identify a commensurate final project experience that could be delivered remotely and relate to chemical process unit operations while maintaining a high level of student interest, engagement, curiosity, and teamwork. [Note: the specific final project assigned during this semester is discussed in the research design section.]

Entrepreneurially Minded Learning (EML)

Over the past few years university members of the KEEN network have focused on increasing an entrepreneurial mindset in engineering students.[15] EML seeks to complement project-based learning (PBL) and active/collaborative learning (ACL) pedagogies to ultimately include value creation and opportunity recognition — a vital aspect of engineering.[16–18] The KEEN network has developed an educational framework geared towards EML. This framework relies on the following KEEN student outcomes (KSO's): curiosity, connections, and creating value, referred to as the 3Cs.[19,20] Applying the EML pedagogy requires a "hook" problem statement and a stakeholder's presence. Previous studies have incorporated EML pedagogy and surveyed students in engineering courses such as fluid mechanics[19] and process dynamics and controls.[21] The evaluation and assessment of KSOs can be challenging for instructors and real stakeholders who might participate in student-led projects. In an effort to assess KSOs, the well-established AAC&U (Association of American Colleges and Universities) VALUE (Valid Assessment of Learning in Undergraduate Education) rubrics were recently adapted to the 3Cs leading to an EML rubric.[20,22] In this study the instructors use the developed EML rubric to assess KSOs in a Unit Operations Laboratory project involving a real community partner during blended learning.

Community-Based Learning (CBL)

The academic connections to a community-based learning (CBL) framework were realized through the ETHOS Center's work at the University of Dayton, which is guided by the best practices and principles of CBL.[23] Community-based learning (also known as community-engaged or service-learning) is a commonly used pedagogy that provides benefits for both student learning and community organizations. The pedagogy requires an experience of engaging with external organizations focused on positive societal change, engaging all participants (students, faculty, and partners) as co-educators and co-learners, integrating critical reflection to generate and deepen knowledge, and connecting these facets with both academic learning and community outcomes.[24,25] The benefits for students involved in community-based learning courses have been well identified, including increased self-efficacy and motivation, development of critical thinking skills, and enhanced ability to apply classroom concepts to real-world challenges.[26–29] These specific benefits align well with the desired student outcomes for open-ended projects. The community partner for this project, Rich Earth Institute (hereafter referred to as Rich Earth), is a long-standing partner of the School's ETHOS Center, thus enabling foundational partnership principles of community/university engagement to be realized even though the project at hand is a one-time interaction. The ETHOS Center establishes and maintains reciprocal partnerships through shared goals around co-educating future engineers for the common good and building capacity for community organizations to advance sociotechnical solutions for community well-being and sustainability.

Community Partner: Rich Earth

Rich Earth, located in Vermont, seeks to convert human waste into valuable resources.[30] One goal is to convert urine into fertilizers, requiring many unit operations, including pasteurization, to treat urine. Past experience and interactions of the instructors with Rich Earth researchers demonstrated that students respond positively to real-world problems posed from their work as a community organization. To this end, a collaboration was already in place with Rich Earth members to improve the urine pasteurization unit's performance at remote sites to locally produce fertilizer from waste. The process utilizes three different types of heat exchanger equipment — including a plate and frame heat exchanger — all of which can be modified for improved operational efficiency and economic benefits.

RESEARCH DESIGN

Final Project

During this semester of blended learning, senior-level chemical engineering undergraduate students worked remotely on a final project in the Unit Operations Laboratory at the University of Dayton involving a heat exchanger unit operation that combined EML and CBL learning aspects. Students were tasked to solve an open-ended problem to improve the heat transfer unit(s) and processes used by Rich Earth during the pasteurization of urine. The students were not given a specific task or deliverable to ensure the open-ended nature of the problem. While the students' work on the final project was completed during remote learning, Rich Earth personnel introduced their organization, the problem statement, and heat transfer processes during in-person learning (roughly two weeks before students transitioned off campus) using a virtual format (Zoom®). Prior to this assignment, the students had eight weeks to experience hands-on learning and worked with various heat exchangers and other unit operations experiments as part of the blended learning approach caused by the global pandemic.

Participants and Teams

In this semester 38 students were distributed in three sections of the Unit Operations Laboratory. Students were divided into nine self-selected teams of 3-4 students each, with three teams in each section for the semester. Only 32 students (50% male, 50% female) provided answers to all surveys or volunteered to be part of this study, and those are included in the results.

Diversity, Equity, and Inclusion Statement

An essential component of engineering education at the University of Dayton includes attentiveness to building an inclusive, equitable, and diverse educational environment. This research study meets several outcomes related to this goal, including the full inclusion of all partners throughout the process of this study — from ideation and design through implementation, evaluation, and manuscript writing. The community partner, community engaged center staff director, non-tenure line instructors, and tenured faculty member brought their diverse perspectives, diverse experiences, and diverse ways of knowing together to collaboratively realize the possibilities of a more meaningful project through engaged engineering education. In fact, it is well documented that community engaged learning in college courses (as was integrated into this Unit Operations Laboratory course) has positive impacts on female students and students of color, including higher retention and success of these students in STEM fields.[31,32] Integrating such a high impact practice into a more advanced engineering course continues to support the University of Dayton's efforts in increasing diversity in STEM, creating inclusive and motivational environments for those who are minoritized, and enhancing equity within local communities.

Indirect Assessment: Surveys and Questions

The self-directed learning readiness scale (SDLRS) was used as a tested survey to determine student readiness for self-directed learning.[11] The SDLRS is a 58-item, 5-point Likert-type scale with scores that range between 58 and 290. Based on Guglielmino and Guglielmino's work, there are three levels of readiness for self-directed learning: below average (58-201), average (202-226), and above average (227-290).[13] The SDLRS survey was given to the students prior to starting the final project. Additional pre- and post-survey questions (Q1-13; Table 1) were given to the students based on previous studies that assess EML and KSOs in other engineering courses. The pre-survey was completed before introducing the final project assignment, and the post-survey was given after submitting the final project and recording the final presentation.[19,21] A Likert scale of 1 – 5 was used to record students' responses for these questions, where 1 = strongly disagree and 5 = strongly agree.

Tables 2 and 3 list the additional questions (QA-N and P1-7) that were added only to the post-survey to assess students' learning impacts and use of the entrepreneurial mindset for this open-ended EML/CBL final project. The student learning impact questions were adapted from a previous study that used a fictional stakeholder[19] and are presented in statement form (P1- P7). The same Likert scale used for Q1-Q13 was used for questions P1-7. Additional questions related to the 3Cs and EML are drawn directly from the KEEN EML framework (QA-QN). The Likert scale used for these questions (QA-N) corresponds to 1= not at all, 2 = slightly, 3 = on some occasions, 4 = many times, and 5 = throughout most of the project. These are also highlighted in Figure 2. Qualitative comments from students were collected to record the benefits and challenges of this experience. These responses were also discussed by the authors of this study considering the community/university partnership shared goals and the student learning and community partner outcomes. A complete list of these responses is available online.[33]

Direct Assessment: KEEN Value Rubric

Students presented their findings to faculty, the community partner, and the ETHOS staff director through recorded presentations and a technical memorandum (maximum of

TABLE 1 **Pre- and Post-Survey (Word Change Reflected in Parentheses) Questions that Evaluate KSOs for the Final Project**
Q1: My professional skills (collaboration and communication) will be (were) enhanced by completing the final project.
Q2: The remote learning experience with Rich Earth will complement (complemented) my hands-on learning experiences performed during the traditional sequence of experiments in the Unit Operations Laboratory.
Q3: I believe that the completion of this open-ended project with Rich Earth will aid (aided) my understanding, evaluation, and selection of heat exchangers.
Q4: The completion of this project will improve (improved) my abilities to anticipate heat exchangers technology trends and developments (including both societal and economic trends).
Q5: The project will allow (allowed) me to explore or investigate technological changes to achieve novel heat exchanger designs.
Q6: The project will help (helped) me in challenging the "status quo" for heat exchangers and explore contrarian views.
Q7: The project will help (helped) me connect information or technologies from various sources (literature, vendors, etc.).
Q8: The project will allow (allowed) me to "think outside the box", seek new knowledge, and integrate technical concepts in a new context.
Q9: The project will help (helped) me to recommend innovative solutions and opportunities for heat transfer applications for Rich Earth.
Q10: The project will allow (allowed) me to explore many opportunities and suggest economic and societal-value solutions to a heat transfer problem.
Q11: The project will help (helped) us to understand value creation and the impacts on others.
Q12: My project could (did) follow untested and potentially risky directions for improving the heat transfer process with Rich Earth.
Q13: This project will help (helped) me to keep engaged and motivated while studying from home.

TABLE 2 **Evaluation of the 3Cs: Curiosity, Connection, and Creating Value (QA-N)**
During the course of this project, to what extent did you:
QA: Explore a contrarian view of accepted (i.e. typical) solutions
QB: Identify an unexpected opportunity for your design
QC: Create extraordinary value for Rich Earth
QD: Integrate information from many sources to gain insight
QE: Assess and manage risk
QF: Persist through failure
QG: Apply creative thinking to ambiguous problems
QH: Apply systems thinking to complex problems
QI: Evaluate economic drivers
QJ: Examine a stakeholder's needs (Rich Earth)
QK: Understand the motivations and perspectives of others
QL: Convey engineering solutions in economic terms
QM: Substantiate claims with data and facts
QN: Work with your team

2 pages), including appendices for supporting information, calculations, schematics, etc. The KEEN value rubric, prepared by Hylton and Hays, was used to summatively assess the work of each team.[22] Results of the KEEN value rubric assessment are used for purposes of this study but only counted for 5% of the final grade, and only the assessment of the instructors was used for this part of the grade. The other 95% of the final project grade was based on components that the instructors identified as critical for demonstrating achievement of course learning outcomes, namely technical calculations and literature reviews, the written memorandum, and the content delivery presented through the recorded video project presentation.

The students' recorded presentations are available through a YouTube™ playlist.[34] A copy of the assignments and the adapted KEEN value rubrics used to assess the reports are available upon request by contacting Dr. Erick Vasquez at evasquez1@udayton.edu.

TABLE 3
Students' Average Rating of P1-P7 Questions Using the Likert Scale, Where 1 = "Strongly Disagree" and 5 = "Strongly Agree"

Assessment of Students' Learning Impacts	Average	Std. Dev.	Agree/ Strongly Agree, %
P1: I believe that my project design satisfied the customer's needs and goals	4.06	0.72	78.1
P2: I consider the results of my project successful	4.28	0.73	84.4
P3: I found my work on the project to be satisfying	3.84	0.81	65.6
P4: The real-world application of the project motivated me to do my best work	4.26	0.77	78.1
P5: The open-ended nature of the project motivated me to do my best work	3.59	0.98	56.3
P6: The presence of a stakeholder (Rich Earth) motivated me to do my best work	4.09	0.86	75.0
P7: The project improved my technical skills in reporting a solution to a real customer	3.81	0.86	68.8

Research Questions

This study seeks to answer the following research questions:

1. Do the students' perspectives for a community-based, final open-ended project assignment for the Unit Operations Laboratories change after switching to a fully remote learning environment?
2. Is the KSO 3Cs KEEN rubric a useful assessment tool for evaluating EML during a remote learning experience in the Unit Operations Laboratory when combined with a remote community partner?
3. Is there a correlation between SDLRS and the KEEN EML student outcomes or the KEEN EML value rubrics?

Study Impacts. To our knowledge, this is the first time that the SDLRS has been compared to KEEN EML student outcomes and assessment tools. It is also the first time that instructors and the community partner collaboratively used an EML rubric to co-evaluate student outcomes. Challenges and benefits are presented for interactions with a community partner during a remote learning environment.

Statistical Analysis

Data were analyzed using OriginPro® 2021. Pre-survey questions were answered by students prior to starting the final project and during in-person laboratory sessions, while post-survey questions were administered to students at the end of their remote learning experience. Surveys were analyzed using Fisher's least significant difference (LSD) pair comparison method. The Pearson correlation coefficient was used to determine correlations between data sets. Significance was analyzed in terms of the p-value, which is presented in the figures and captions.

IRB Approval Statement

The institutional review board at the University of Dayton approved this research and allowed students' participation. Students signed a voluntary consent form to be part of this study, and results of pre- and post-surveys, as well as the SDLRS scores, were held from the instructors until after semester grades were finalized.

RESULTS

The average results from the pre- and post-surveys (Q1-Q13) are shown in Figure 1. A traditional Likert scale was used for data analysis, where 1 = strongly disagree and 5 = strongly agree. As observed, for all the survey questions, students had lower average responses after completing the project. Significant differences, p-value <0.001 (***), were related to Q3, Q5, and Q10. These differences are related to questions about improving their learning on heat exchanger design and adding innovative solutions and opportunities to heat transfer applications for Rich Earth. Additionally, students' average responses were different, p-value <0.05 (*), for Q1, Q2, Q6, and Q13. Q13 relates to engagement and motivation while being in a remote learning environment. For this question, only 48.5% of students strongly agreed or agreed that the project helped keep them engaged and motivated while working from home (post-survey). Although the result is discouraging, it was not entirely unexpected as discussed next.

The in-person laboratory course experience had eight weeks of hands-on learning prior to the transition to fully remote learning. Initially, we believed that this transition may have had a negative impact on the students' motivation to put forth earnest effort on this team's final project. As discussed through a conference session hosted by the Learning and Teaching Center at University of Dayton, the lack of motivation and the ability to maintain learning productivity once students transitioned to a remote learning environment were also noted by many faculty members from across campus, regardless of pedagogical methods being used to engage students. For laboratory-based courses, the transition from hands-on education to a more abstract situation may have also presented additional challenges.

Students' average ratings and standard deviation responses for questions P1-7 and response percentages attributed to "agree" and "strongly agree" for each of these questions are shown in Table 3. Based on the survey responses, students were motivated to work on a real process with an external community partner for the final project in the Unit Operations Laboratory. Approximately 78% of students either strongly agreed or agreed that the real-world application motivated them to do their best work (P4), and 75% of students strongly agreed or agreed that the partnership with Rich Earth was a positive motivation factor (P6). Furthermore, 69% of students either strongly agreed or agreed that reporting to a customer improved their technical skills (P7). These results are encouraging in that they support anecdotal observations that students tend to be more motivated and put forth more effort when tasked with a real external project. Based on our observations, by senior year, students are tired of solving repetitive problems and projects originating from textbooks or instructors that are primarily abstract. Instead, they are eager to work on something where the product of their work has a "real-world" application. Qualitative student responses supported this statement (e.g. "*I liked delivering a product that has tangible results for an organization whose message and core values I connect with*" and "*Seeing how our classwork can apply to real companies, especially companies trying to make the world a better place*").

Despite the positive feedback above related to student motivation for this external collaboration with Rich Earth, only 56% of students strongly agreed or agreed that the open-ended (P5) problem motivated them to do their best work. In fact, students' average ratings were also the lowest for P5 (Table 3). The presence of a real stakeholder (P6) seems to improve the motivation on performing the work, which is a new insight gained on this work as compared to a previous study presented by Gerhart and Melton on which a fictional stakeholder was provided to the students.[19] Qualitative comments reinforced these observations confirming the lack of hands-on opportunities to physically interact and observe the equipment functioning as well as the lack of continuous in-person communication with Rich Earth personnel or the instructors during remote learning. A complete summary of the qualitative responses is available online.[33]

Percentages and average results for the evaluation of the 3C's (QA-QN) with the rating scales are shown in Figures 2A and 2B, respectively, where 1 = not at all and 5 = throughout most of the project. Based on this Likert scale (also described in the Methods section), results indicate that most students faced KSOs at least occasionally during the completion of the final project in a remote learning environment. The survey revealed that ~ 85% of the students (QN) worked in a team while completing the assigned task many times or throughout most of the project, implying that student interactions persisted during remote learning. Lower mean and standard deviation values were found for QA, QB, QC and QE. As shown in Table 2, these questions relate specifically to high-risk solutions and unexpected opportunities provided to Rich Earth. Average results of this survey, shown in Figure 2B, agreed with the average values reported for a

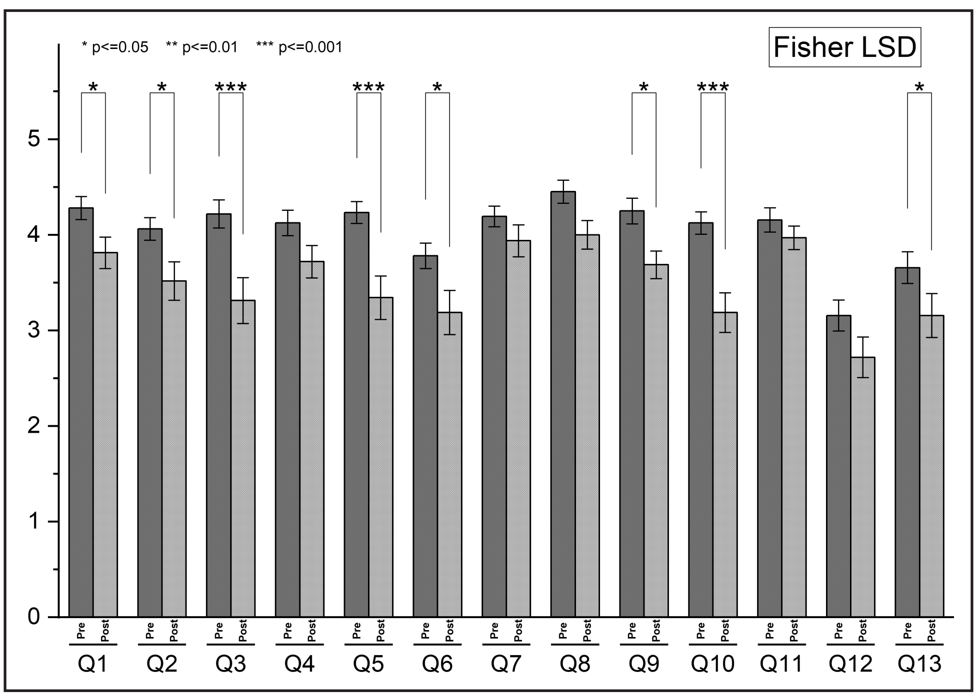

Figure 1. *Pre- and post-survey questions (Q1- Q13) examined the students' interests in heat exchanger designs and KEEN student outcomes in a remote learning environment [* p <=0.05 **; p <=0.01 ***; p <= 0.001].*

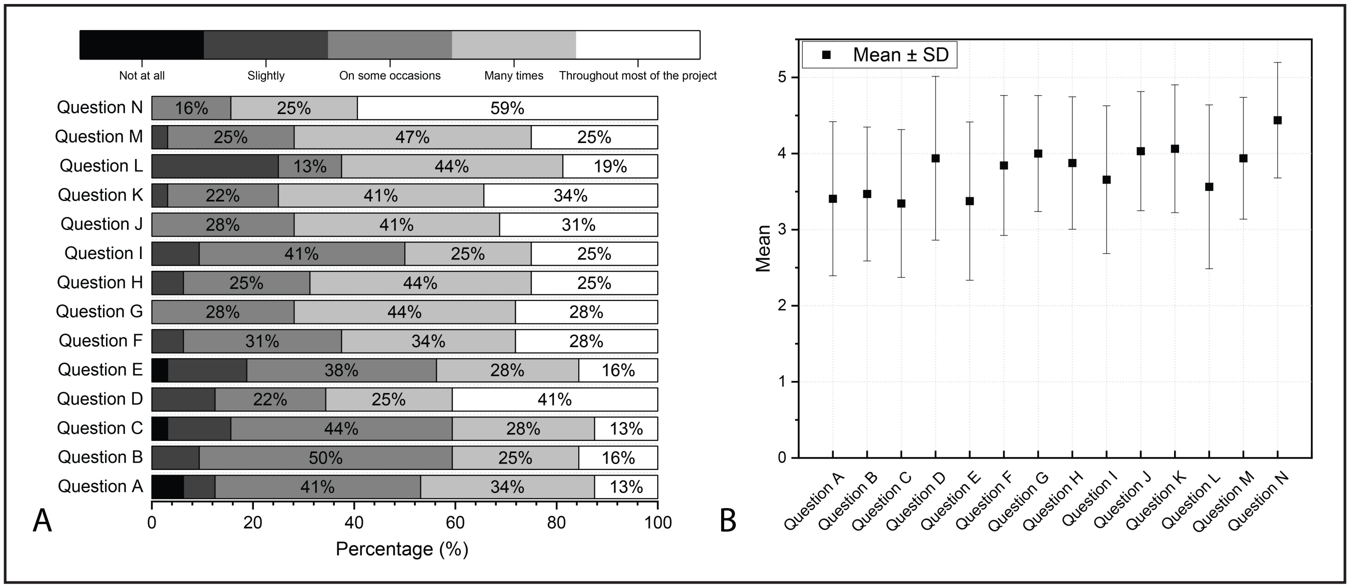

Figure 2. KEEN student outcomes (KSOs) survey questions (QA-QN) after the completion of the project. Panel A shows the students' response percentage to values of 3 – 5 from the Likert scale, and panel B shows the mean with average results for QA-N (Note 1 = Not at all, and 5 = Throughout most of the project)

fictional stakeholder presented in a previous EML study.[19] Thus, based on responses for P1-7 and QA-N, we can infer that the presence of a community partner or a real customer provides insights that allow the analysis of EML and KSOs.

The students' SDRLS average score and standard deviation was 235 ± 24. The skewness value for the survey was -1.39, revealing that the results for this survey skewed towards the right. A Kurtosis value of -0.088 was also found, indicating that the collected data is light-tailed relative to a normal distribution. The negative sign of skewness suggests that the results for SDLRS on the students are on the high-end values, revealing that the students in the laboratory had an above average readiness for self-directed learning based on the interpretation of the scale.[31] In this study we attempted to correlate SDLRS individual scores to the students' survey responses, and the results are shown in Figure 3. Additionally, we present results that show the positive and negative significant correlations among different questions based on p-values obtained from this work. Correlations among questions for each survey are shown to aid future implementations of these surveys. As an example, Q12 does not provide significant correlations with any other questions (Figure 3A) and could be avoided in future surveys. This analysis, however, is beyond the scope of this work, and our focus is to gain a direct understanding of correlations between SDLRS and the survey questions.

We found that negative significant correlations existed between the SDRLS and Q1, Q8, Q9, and Q11 (Figure 3A). These questions were used to assess KSOs related to improve communication and collaboration (Q1), think outside the box (Q8), recommend innovative solutions and opportunities (Q9), and understand value creation and the impacts on others (Q11). Individually, these negative correlations confirm that SDLRS results impact KSOs. On the contrary, positive correlations were observed between SDLRS values and creative and systems thinking to ambiguity and complex problems, and engineering solutions in economic terms (QG, QH, QL; Figure 3B). Moreover, as shown in Figure 3C, the results confirmed the SDLRS values correlate to the open-ended nature of the project (P5) and technical skills developed in reporting a solution to a real customer (P7).

The average SDLRS scores for each team were also calculated and compared to the average scores that came from using the KEEN value rubric assessment of the final project memorandum and video (out of 110 points). Correlation results are shown in Figure 4. It is important to note that the KEEN value rubric assessment (abscissa) only contributed to 5% of the final students' project grade, and the presented values are the average scores of three instructors of the course. Results indicate a linear relationship between SDLRS team average scores and the KEEN value rubric team evaluations performed by the instructors (n = 3). This correlation suggests that teams with average higher SDLRS scores generally scored higher on the KEEN rubric (Pearson's r value of 0.55). Further research is needed to determine if the rubric favors those with higher SDLRS scores or if those with higher SDLRS scores are more likely to also exhibit entrepreneurial mindset attributes. The open-ended, EML nature of the project as well as the presence of a community partner are key components that are discussed next.

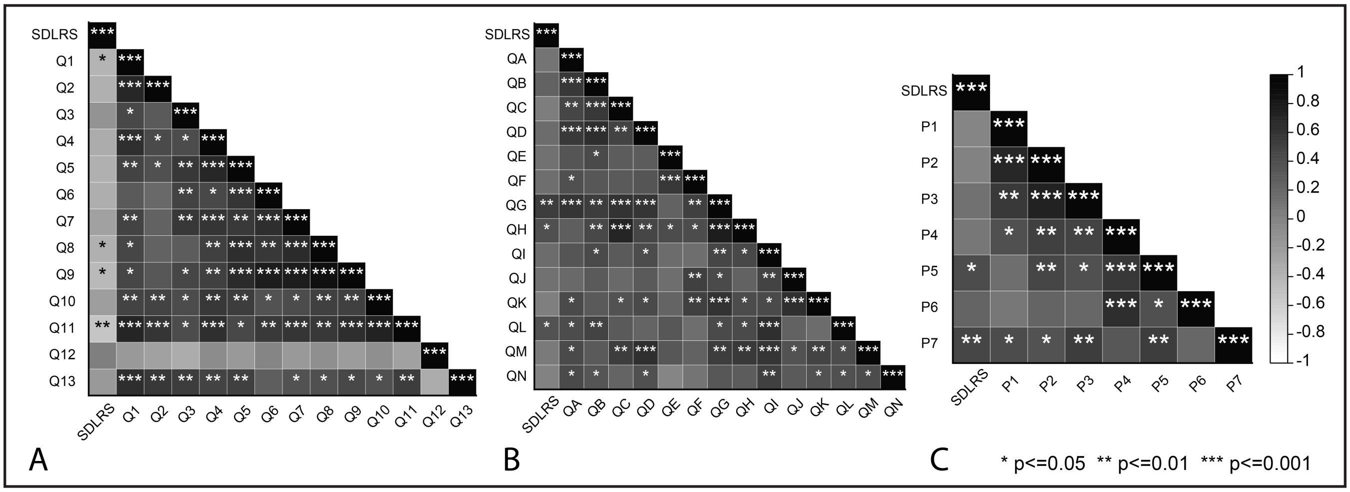

Figure 3. *Obtained correlations of individual SDLRS values with survey responses provided by students in the Unit Operations Laboratory after completing a remote, open-ended final project experience. (A) shows results for Q1-13, (B) represents the results for QA-N, and (C) shows the correlations for P1-7.* [* p <=0.05 **; p <=0.01 ***; p <= 0.001].

DISCUSSION

As part of the community/university partnership, the authors leveraged assets, shared concerns and insights, and collaboratively ascertained the benefits and challenges of both partnership work and the use of EML pedagogy in an open-ended, remote laboratory final project. We engaged in conversations about the entrepreneurial mindset's applicability and the readiness for self-directed learning for achieving intended student learning outcomes and community partner outcomes. Open conversations involving our own curiosity, connections, and creating value generated authentic feedback from the community partner's perspective and ideas for instruction-related components in future courses.

The authors of this study were tasked to evaluate each project based on the EML 3Cs value rubric. Rich Earth personnel and the ETHOS center director were unable to assess the rubric's curiosity and connection components due to a lack of direct contact with the students. Rich Earth personnel interactions with students were limited to an initial remote video presentation and follow-up answers to questions compiled from all students that were sent via e-mail. The community partner is a small, non-profit company, and the staff time needed for initial one-on-one interaction with each of the nine teams, and further consistent feedback, was limited. During authors' reflective discussions, Rich Earth personnel shared that community partners often weigh the benefits of working with students on projects, co-educating, and forming future engineers and the costs of lost mission-directed work time.

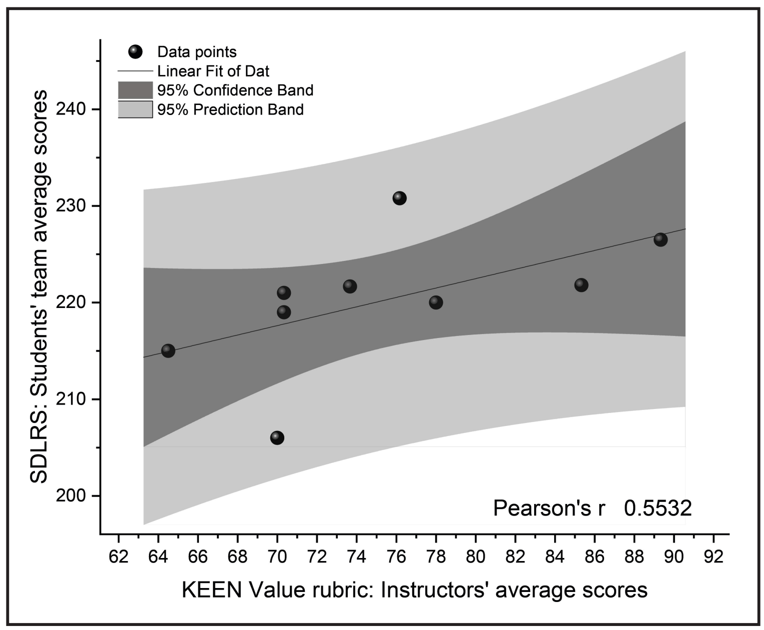

Figure 4. *SDLRS team average scores compared to the average KEEN VALUE rubrics (out of 110 points) scores assigned by the instructors (n =3) of the course.*

For Rich Earth the open-ended nature and focus on EML aspects of this project created more uncertainty in the cost/benefit analysis because of the unpredictability regarding direct applicability of the results and time investment. On the contrary, they agreed that consistent results not immediately valuable could still offer new insights and connections for future innovations, which is always a benefit, as is learning more about students who could make great future ETHOS center immersion interns.

From an academic standpoint the combination of positive and negative significant correlations between SDLRS and the students' responses to the survey questions (Figure 3) provide significant challenges to future EML-type studies conducted in a remote setting with a community-partner. For instance, we incorporated this study during the Unit Operations Laboratory, which is a senior-level course, and evaluated the SDLRS scale at this point. Perhaps implementing more EML-style activities throughout the curriculum and monitoring SDLRS scores could help the infusion of EML to students. Based on this work, students' qualitative responses provided additional significant insights about the project and further challenging aspects. A vast majority of the students related their positive experience to work with a real community partner that will potentially use the proposed solutions. Some students also correlated the project's open-ended nature to creative solutions in terms of social and economic factors. For example, out of the nine projects, two team reports suggested implementing an immersed coil heat exchanger as part of the proposed solution. Rich Earth personnel independently identified a coil heat exchanger as a potential solution to their current heat treatment needs. Conversely, students considered time allocation and lack of communication between all the parties involved as well as the remote setting as obstacles for the completion of this project as shown in the survey responses.[33]

Despite these challenges, the students presented various heat transfer solutions, suggesting that they employed their curiosity in solving the problem. The varied number of heat transfer solutions also revealed students' misconceptions about the current heat exchangers' components and functions at Rich Earth. Students commented that it would be helpful for the community partner to provide written documentation and a deeper description of the system's operation, and some students requested specific problems to be solved; however, solving a specific assigned problem would limit the 3Cs aspects of EML. Discussions with Rich Earth personnel determined that their presentation and operational data could have been supplemented to provide a more comprehensive system operation description. Increased communication, such as a second round of question and answer with the community partner, may have been able to resolve student misconceptions of the process and may indicate additional guidance towards mutual goals. We suggest that ongoing communication among all the parties involved — students, community partners, instructors — is fundamental for successful EML/CBL projects. A balance of the appropriate amount of partner time spent with students must exist to provide meaningful solutions to an actual community partner with specific technical goals to open-ended creative designs.

The student statements are consistent with instructors' observations that open-ended projects in the chemical engineering curriculum can be less popular with some students. This is due to factors including the lack of a set solution procedure, ambiguity involved in developing the technical approach, and insufficient time to allow detailed analysis and review. This observation is further exacerbated by not seeing or using the heat exchanger unit operation, as evidenced in the following student responses:

> "*There was not a lot of time to develop solutions, visualization of the system and the true issues were not clear.*"

> "*We didn't have much opportunity to communicate with Rich Earth personnel after the initial meeting, and it would have been very nice to do that.*"

Several students shared feedback about appreciating engagement with a community partner, and some further added a desire for more time with the partner to ascertain what is contextually applicable to them and how a solution could connect to their funding and future goals. The students who often made these comments were seven students who had previous ETHOS center experiences, two having participated in a 10-day breakout, and five having participated in one or more semester-long, sociotechnical immersions. Many of these students stood out to the researchers when evaluating their final project deliverables using the EML, 3C's rubric, without most of the authors knowing these students had experience with the center. The researchers noted that these students made deeper connections, desired a more profound commitment to the partner and the project, and leveraged their assets (curiosity, self-directed learning, creative problem solving) to their teams' advantage. Furthermore, the team that scored the highest on the EML rubric had two team members with ETHOS center experience, and two of the other three students with ETHOS center experience were a part of the team with the 4th highest score.

Continuous student performance evaluations are part of the ETHOS center efforts. Work-in-progress evidence suggests that students have further developed their intercultural effectiveness skills, sense of self-efficacy, and critical thinking skills upon completing an immersion and incorporating the entrepreneurial mindset. This would align well with extensively published research demonstrating the correlation between community-engaged learning experiences and outcomes of critical thinking, self-efficacy, etc.[26–29]

Implementation Challenges and Suggestions for Future Studies

Future open-ended, EML/CBL learning implementations can benefit from this study in fully remote or blended learning experiences. Despite the constraints encountered, we believe that these types of CBL/EML partnerships can help students achieve learning outcomes and have more motivation when access to hands-on laboratory equipment is not available (i.e. a fully remote learning situation). Through a critical reflection we discussed the difficulties of community partners engaging valuable resources, such as time, for CBL projects and how this limited their ability to be more fully involved as co-educators and co-owners of work processes and products.[32] Together we learned about the intricacies of reciprocal partnerships, guiding students in uncertain times, and the educational value of addressing authentic, socially responsible challenges. To implement successful EML/CBL studies while in a remote setting for any of the parties involved, we suggest the following:

- Constant communication, such as regular constructive feedback, is vital among all parties involved, including students, community partners, and instructors.
- Students should have access to technical diagrams of the unit operations equipment to be modified, improved, optimized, or re-purposed, such as a plate and frame heat exchanger with similar characteristics.
- The community partner should provide detailed written technical information on the equipment's process, constraints, flow diagrams, and sample operational data. A video explaining the unit operation and specifying inlets/outlets could aid in understanding the process.
- A planning process (e.g. a Gantt chart) is needed to schedule interactions between community partners, students, and instructors and regularly evaluate progress. The timeframe should include weekly meetings and educational/mentoring opportunities provided by the community partner. Constant, direct interactions between students and the community-partner leverage learning experiences and creative processes for future project explorations. A stipend should be allocated to non-profit/small-business industry partners to alleviate financial and time distresses caused by multiple student teams' presence and acknowledge their essential role as co-educators. This stipend will help the community partner better justify their time spent with each team to address potential misconceptions or aid the community partners' technical needs that align with the 3Cs.
- Allow sufficient time to complete the project without disruptions. In a fully remote learning experience, the authors believe that individual modular unit operations investigation can enhance student learning opportunities (e.g. pipe flow, heat exchangers, and chemical separations).
- Assess the students' interest and capacity for success with open-ended projects through validated surveys, such as the SDLRS scale, or through team-formation approaches that include students with previous community-based learning experience with institutions like the ETHOS center or Engineers Without Borders.

CONCLUSION

This study concludes that the transition to remote learning after a hands-on experience in the Unit Operations Laboratory involving a unique, open-ended problem statement with the presence of a real community partner was not favorable from a technical or hands-on perspective for all students. Nonetheless, EML/CBL aspects implemented through the proposed open-ended final project helped engage students' teamwork, motivation, and interactions during remote learning. We also demonstrated a correlation between self-directed learning, open-ended projects, and the KEEN student learning outcomes of curiosity, connection, and creating value. An actual client can leverage remote-learning experiences; however, logistics must include the partners' time devoted to the project and educational and mentoring aspects. Similarly, all the parties involved, including students, instructors, and stakeholders, must define mutual technical goals that align EML with the client's needs. In addition, the community partner must provide continuous feedback and suggestions that align with pursuing mutual goals. Finally, a potential stipend for a non-profit/small-business partner and constant, direct communication throughout the project can enhance students' educational components of the open-ended KSOs of curiosity, connections, and creating value.

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