

COMPARING LEARNING IN UNIT OPERATIONS COURSES ACROSS THREE MODALITIES: DOMESTIC, FOUR-WEEK STUDY ABROAD, AND EIGHT-WEEK STUDY ABROAD

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INTRODUCTION

To help prepare engineering students for an increasingly global workforce where working on multinational teams is common practice, engineering programs seek ways to help students develop the competencies required to succeed in such settings through opportunities such as study abroad experiences.^[1] Studying abroad, a form of experiential learning, has proven effective in developing engineering students' skills in communication, empathy, and taking on diverse perspectives before entering a globalized workforce.^[4] When designing these programs, universities have goals for students to gain specific competencies or mindsets. For example, immersive exchange programs can be a way to help students rapidly develop intercultural and language skills. However, this type of program can be difficult to implement in a chemical engineering curriculum.^[2] In this paper we present an analysis of the experiences of chemical engineering students who could select from one of three options for their required summer Unit Operations (UO) lab course (Table 1): (1) a lab course at their home campus in the United States (pseudonymized as U.S.U.), (2) an eight-week long exchange program with a German university (pseudonymized as UGermany), or (3) a stand-alone four-week summer course offered at a university in Denmark (pseudonymized as UDenmark).

The unit operations lab course is a significant transition point in the chemical engineering curriculum, and at U.S.U. it is taken during the summer before the final year. Students apply their theoretical knowledge to hands-on projects related to physical and chemical transformations as they develop teamwork skills and prepare for the workplace transition. At U.S.U. the students complete eight hands-on labs while being supervised by different graduate teaching assistants.

They also have access to a professor who is the head instructor for the course. In the UGermany program, U.S.U. students take the UO lab course from UGermany professors alongside a few UGermany students for eight weeks in the summer and receive exchange credit for the course. This course requires the completion of six lab activities. Outside of the course, the students also complete 50 hours of work

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| <i>University</i> | U.S.U. | UGermany | UDenmark |
|----------------------------|--|--|--|
| <i>Number of Students</i> | 50 students | 11 students | 24 students |
| <i>Length of Program</i> | 6 weeks | 8 weeks | 4 weeks |
| <i>Group Assignments</i> | Groups of 4 Choose 1 U.S.U. partner, assigned another pair | Assigned 2 U.S.U. students and 1 UGermany student | Choose 1 U.S.U. student |
| <i>Number of Labs</i> | 8 labs | 6 labs | 6 labs |
| <i>Time Spent per Week</i> | 40 hours | 12-15 hours | 40 hours |
| <i>Other Assignments</i> | Oral presentations of work | 50 hours of research | 50 hours of research |
| <i>Grading</i> | A-F, graded by U.S.U. faculty or teaching assistants | Pass/fail, graded by UGermany instructors | Pass/fail, graded by U.S.U. faculty |

on a research project with UGermany graduate students. UDenmark offers its Large-Scale Chemical Unit Operations summer course annually to international students. The program is four weeks long, and a U.S.U. faculty member travels with the students to grade their work. The course is conducted in a dedicated practice lab space and the students can select a set of six labs that are approved by the U.S.U. professor as qualifying for transfer credit. The students are taught by UDenmark graduate students and faculty; in the year of this study, students from multiple US universities enrolled in the course. Since the courses abroad have fewer labs, the students were required to complete a 1-credit course with additional labs at the home institution during the following semester.

The purpose of this multi-case qualitative research study is to describe in detail three cases of students' experiences in a unit operations lab course, paying particular attention to the potential for achieving development along a variety of learning outcomes associated with preparing students for a globalized workforce beyond the specific objectives of the standard UO lab. Through the framework of the zones of proximal development, we categorized students' descriptions of their learning to discover how programs' designs combined with an appropriate amount of support can encourage student learning. This study's two research questions are as follows:

1. What do students value from their experiences when taking a Unit Operations lab course while studying abroad or at home?
2. How does the amount of support they receive, as interpreted by the zones of proximal development, affect what and how students learn?

LITERATURE REVIEW

For decades, institutions and companies have called for chemical engineers to be educated in a more cross-cultural perspective.^[3] Students learn in both formal and informal spaces when studying abroad, adapting to new cultural expectations in the classroom while learning how to navigate day-to-day challenges that they take for granted in their home context.^[5] Short-term programs are less than eight weeks long and have demonstrable personal and professional benefits, although they are often less pronounced than long-term programs.^[6] However, there is a need to further examine the learning students experience while studying abroad, in particular, related to global engineering competency outcomes.^[7]

Because the chemical engineering curriculum is highly sequenced, it can be challenging to build study abroad into students' plans of study.^[8] It can be particularly difficult to find equivalencies to lab courses in chemical engineering abroad.^[9] It is therefore not surprising that STEM students only make up about 5% of students studying abroad annually.^[10] Given these constraints, institutions try to find ways to provide engineering study abroad experiences that encompass technical course requirements. Our study compares student experiences in different versions of the same technical lab course (i.e., the traditional domestic version as well as two international versions). This research design is similar to a prior study comparing the outcomes of a senior mechanical engineering capstone course offered at students' home university or as a six-week study abroad project in Mexico.^[11] The results from that study illuminated stresses of learning in a different country with cross-cultural teams but also the significant learning that came along with working in diverse teams with a language barrier.^[11]

THEORETICAL FRAMEWORK

The qualitative analysis in this study was informed by the sociocultural learning theory of zones of proximal development (ZPD) and Senninger's interpretation of the ZPD, which redefined the theory into three distinct zones: comfort, learning, and panic.^[12, 13] This theory posits that students learn when they are challenged to an appropriate level. In the comfort zone, students perform activities based on their prior knowledge and do not need new skills. On the opposite end, in the panic zone, students are overwhelmed to the extent that they become unmotivated and cannot overcome the challenge to learn. Students acquire new knowledge and skills in the learning zone, where they are doing new things but are set up to stretch and then succeed.^[14] Some scholars have conceptualized ZPD as an intrinsic trait for learners that influences their self-efficacy.^[15] Others believe instructors can assist students in moving through the zones. Similar to this study, Fila et al.^[14] analyzed student interviews about innovative projects they had worked on to identify their experiences with innovation in each zone.

RESEARCH METHODS

We designed a multi-case study to explore students' experiences in a multi-location UO lab course.^[16] Here, each case is a version of the course taught at a different university in a different national context. Students in each of the three options were interviewed about their experiences, learning, and feedback through semi-structured interviews. The data were supplemented by researchers' observations and documentation of each course and university. The ZPD theoretical framework informed the approach to qualitative data analysis, which was open coding by theme and categorization of quotes.

Data Collection

The participants in this study can be considered to be part of a single population: chemical engineering undergraduate students enrolled at a single US institution. Most of the students had completed their third year in the program, although a few students in the U.S.U. track had finished their fourth year. The year of data was atypical for having a few fourth-year students in the course because the students were allowed to delay the UO lab course for a year due to pandemic accommodations. If a student delayed the UO lab, they were required to take the U.S.U. course. All students were invited to participate in the study, resulting in a voluntary response sample of five participants from the US site, six from the Denmark site, and seven from the Germany site. We consider that we had sufficient students from each site to capture the broad aspects of the experience, although we

acknowledge (note the data in Table 1) that many more students were in the U.S.U. course than the two study-abroad options.

Two previous studies examined the factors that influence students' decisions of which UO course to enroll in.^[17, 18] Future career opportunities, personal connections, and financial support were significant factors.^[17, 18] All three versions of the course are taught in the summer and require the payment of additional summer tuition, which students in all courses described as a financial burden. Some students chose U.S.U. because it was the cheapest. In an attempt to make the program more accessible, all students who studied abroad received a scholarship of \$600 (UGermany) or \$1000 (UDenmark). However, the out-of-class costs were still significantly greater for the students who went abroad. The study abroad students often discussed costs and said that they chose the cheaper of the two study abroad options. Because of the exchange structure, the tuition costs were the same in UGermany and U.S.U., which was a benefit for in-state students. The students at UDenmark were usually out-of-state students who said that the tuition costs were similar to taking the summer course in U.S.U. Overall, the students are not randomly placed, but we believe that the research results still largely reflect these different educational (or learning) experiences. We do acknowledge the potential for differences in financial situations to potentially play a role in placement on ZPD, although we did not observe such a pattern in our data.

The primary data source is 20 – 45-minute interviews that were conducted with the participants mid-program. The interview protocol was based on a protocol that has been used previously to explore an international research program.^[19] Sample baseline questions included, "Can you tell me about your experiences within the lab class so far?" and "How has the lab changed or expanded your understanding of what it means to be a chemical engineer?" There were additional international-specific questions for the students studying abroad, such as "What prior international experiences have you had?" The students were also invited to participate in a follow-up interview after the program, and while there were fewer participants in this phase, these data were also used. Two participants from UGermany and one from UDenmark participated in the post-program interview.

All interviews were audio-recorded and transcribed, with the students' consent following approved IRB protocols. The transcriptions were analyzed for this study. Supplementary data sources included documentation and researcher observations based on site visits.

Data Analysis

The interview transcripts were analyzed with standard qualitative data coding.^[20] The a priori code categories were Chemical Engineering Lab Skills, Cultural Interactions, and

Extracurricular Activities. Each interview was analyzed individually to group students' experiences in the three code categories. Once the coding was complete, relevant quotes were compiled for each case and labeled by code and relevant program aspects, and the data were analyzed through the ZPD framework.^[12-13] We analyzed each theme for each case based on a high-level interpretation of which zone of proximal development the students experienced.

RESULTS

In this section we present the results of the analysis of student experiences, taking this context by context, working within the high-level categories, and identifying the relevant ZPD across each of these. Table 2 gives an overview of these findings.

U.S.U. Student Experiences

Chemical Engineering Lab Skills. The students in the US track described the workload in the lab course as intense, and early in the program they felt overwhelmed, which we identified as panic. Each project requires about four hours in the lab, and the rest of their time is spent in write-up and preparation for the next lab, with work occasionally continuing into lunchtime and the evening. Over time, students grew more comfortable writing the reports, which allowed them to move from the panic zone into the learning zone and advance their time management skills. One student described plans to reference their growth in future job searches, saying, "I think there's a lot of stories for interviews in terms of group work and group dynamics, getting things done for a deadline... It was a lot of multitasking being on a time constraint and having to do the pre-lab and finish the report while doing the next experiment."

A repeated theme was inconsistency in the labs' difficulty and open-endedness. This inconsistency can be partially attributed to different teaching assistants (TAs) managing each lab. One student described having a few good experiences, but overall, this kind of comment showed the students' panic: "Generally, I did not think the TAs were very helpful. I thought that most of them would barely understand or be

able to give valuable feedback on our preliminary reports and show us the equipment and most of (the labs) my group felt like we were completely figuring it out on our own once we got into the experiment on our first day." Students also felt that some of the instructors were more helpful than others, noting that some did not give feedback on their grades. The students expressed a desire for more assistance from the instructors, and many were entering the panic zone in their preparation for the labs. It is difficult for course instructors and students to find the balance between autonomy and support in learning. Many students did not think that the right balance was offered for every lab, leading to them growing comfortable with close-ended labs and panicking when other more open-ended labs required the students to design the experiments.

Along with the differences in instructors, students noted that the equipment for some labs was unreliable. Students were given pre-made example data for their analysis when the lab equipment failed. This situation limited their learning compared to performing the experiment themselves. When the equipment was working correctly, students were in the learning zone as they applied their theoretical knowledge to design lab procedures. One student described the hands-on aspects of the class as providing a unique learning experience, saying, "I also think that none of the other classes... make us think in that way, if that makes sense. Even if you take a lab class, they don't ask you why the data went that way, you don't learn the theory, and then you don't compare them, so this is a different way of thinking."

A case of students not practicing their independent lab skills was illustrated in one student's description that their class had shared procedures between groups instead of the groups independently designing the experiment. A student described this dynamic as, "I don't know if (the labs) were necessarily very open-ended because we had a list of objectives that we had to meet, so there were only certain ways to meet those objectives, and this was (the TA's) first time participating in the lab. So basically, the first group figured out what to do and then everyone else kind of based it off of that, so it wasn't like there was that much variation between each group unless they messed something up." Copying procedures from other groups impeded students' creative and critical thinking and kept them in their comfort zone.

TABLE 2
Summary of ZPD Coding Results by Case

| Coding Categories | U.S.U. | | | UGermany | | | UDenmark | | |
|-----------------------|---------|----------|-------|----------|----------|-------|----------|----------|-------|
| | Comfort | Learning | Panic | Comfort | Learning | Panic | Comfort | Learning | Panic |
| Lab Skills | X | X | X | X | X | X | | X | |
| Cultural Interactions | | | | | X | | X | X | |
| Extracurricular | X | | | | X | | X | | |

Learning how to collaborate with a group of peers is an important lab skill from the UO course. Students completed the lab assignments in groups of four. They were able to choose one partner and were paired by the instructor with another duo. Group dynamics were the most common frustration for students in the course in this setting. Many felt that not all team members contributed equally. One student speculated that students with high grades were purposefully paired with those with low grades (although instructors do not have access to student grade point averages). The students who agreed to be interviewed all felt they were doing more than their fair share of work. It seemed that students were often in the panic zone. Instead of learning how to collaborate with their group, they stated that they would rather finish the work alone. One student stated that doing the calculations alone had led to a deeper understanding of the materials. Another student summarized their experience with the group dynamic as, *“I wish there was some way to make it more even. It ended up being a lot of work for me and my friend... you have people that have different expectations, so some people just want to pass, but then their attitude affects the work of the people that want to try to get A’s.”* Students overall did not state that their teamwork skills were improving and seemed to instead remain in the panic zone, although one student said that they thought they could apply what they were learning about how to incentivize team members to future leadership roles.

This course required oral presentations of work in addition to technical reports. Students rarely mentioned learning from these presentations. One was pleased with the opportunity to practice presenting and writing since they said the technical information had been covered by their co-ops: *“Oral presentations, I think I’m maybe less nervous, or at least I know how to calm my nervousness you know, take a deep breath. And then I think about written reports, I definitely figured out how to write a report or a memo.”*

Extracurricular Activities. With respect to location, the students seemed to be in their comfort zone living in their university’s town during the summer. Most students had lived in the town for multiple years, and their environment did not significantly change by staying for the summer. They were also more likely than the other site options to interact during the course within their usual social circles. A representative quote was a student saying, *“We’re all here together, we’re all going through this tough class together, so I organized a couple of things to do. We went downtown a couple of times.”* No one said that they were learning from these experiences, however, though they enjoyed the local activities.

Summary. Overall, the students who remained at U. S.U. were comfortable with their location and university experience. They did not describe cross-cultural learning.

They experienced panic when there were significant issues with laboratory equipment and teamwork and were not given the support they needed to learn from these situations. For the labs’ instructions, the students felt panic when they did not understand, and some groups chose to copy procedures, limiting their own stretch. The lab reports were in the learning zone because it was initially difficult, but the students adapted to learn how to complete them.

UGermany Student Experiences

Chemical Engineering Lab Skills. The amount of time devoted to the course changed for students in UGermany as they progressed. Most students had no coursework responsibilities for the first four weeks of the eight-week program because of pandemic complications. Since students were not finishing labs early in the program, students had three or four labs per week at the end of the program, including one on the day that students had planned to fly home. Several students were in the panic zone when it came to finishing these labs. Some decided it would not be worth the cost to change flights and elected to receive a zero for the final lab since the course is graded pass-fail for the UGermany option. Students also described working through jet lag to finish the report for the last lab once they got home. The students were in the panic zone in some cases and gave up on finishing the course work, which impacted their potential to learn technical content.

The students had mixed experiences with the lab assignments. Students said they did not receive feedback on their work along with miscommunications about scheduling their lab. Similar to the U.S.U. track, one group experienced equipment failure that led to them being given data instead of generating the data in the lab setting. They also described the lab procedures as prescriptive, which kept them in their comfort zone, with one student saying, *“Mainly we were just told what to do pretty much. So I learned how to use the equipment but it wasn’t much critical thinking on designing experiments.”* Each lab was taught by a different TA who was unfamiliar with the students’ prior knowledge from earlier portions of the course. However, the students were appreciative that they were learning how to use new lab equipment. One student took a positive perspective on the difficulties in the lab and stated, *“Stuff will go wrong, and being able to adapt was a big part and troubleshooting... A lot of the labs I assumed from the pre-lab we were going in collecting this data, and it should look like this and a lot of the times it really didn’t come out that way. We still got usable data, but it deviated. So, then it was really cool applying all like the error analysis and figuring out what went wrong. I think I learned a lot there.”* Students had the opportunity to stretch themselves by learning from the difficulties in their lab, as they will have to do in the workplace.

The students were assigned groups of three to complete the lab work. UGermany students could choose to take the course in German with their peers or in English, alongside the U.S.U. students. The U.S.U. students expected that each group would have one UGermany student. With the program restarting after a pause during the pandemic, there were only a few UGermany students in the course, so some groups were all U.S.U. students. Since they were taking the course in English, UGermany students did not have to complete as many labs as the U.S.U. students, which one interviewee noted as being confusing logistically with additional difficulties sharing responsibilities, saying, *“I felt like (the UGermany student) was unprepared a lot at times, and then the TAs would chalk it up to being like: ‘Oh, well, just because it’s in English’ and kind of bailing him out a little bit. But yeah, I definitely felt like he didn’t really pull his weight in the group when we did work with them.”* Since the labs had been delayed, the teamwork experiences students had by mid-program were limited. These students were neutral to negative about their group work experiences. By the post-program interview, the participants did not highlight learning from their teams.

This program is the only one to include a research experience. Students received two course credits for participating in 50 hours of chemical engineering research spread throughout their time at UGermany. The students said that they felt as if they were lab assistants in their research program, not researchers. They completed tasks for graduate students, but they did not have autonomy in their work, keeping them in the comfort zone as researchers. Regardless of their actual learning, almost all students were glad to have this experience for their professional development, particularly if they were interested in graduate school. One student stated, *“Professionally, I really like the undergraduate research part. I can put that on my resume and a lot of the recruiters I’ve talked to, they all say because of that and some other experiences I’m more geared towards an R&D position.”*

Cultural Interactions. The students described observing specific German cultural differences and learned to navigate within and beyond the context of the university. The aspects they mentioned included punctuality and environmental consciousness. Some described experientially learning from their own social gaffes, and several discussed applying their knowledge to future global workplaces. An exemplar quote is, *“I would definitely say that I’m improving in understanding different cultures, especially German culture and seeing where they come from an engineering standpoint. And once I get to the lab and my research, I’ll be able to gain a better understanding of how that incorporates into engineering, which I’m excited to do.”* Another student said the ability to work cross-culturally was important for engineers and something they would highlight in future job interviews. A significant aid to their cultural learning was that U.S.U.

students had coordinated events with UGermany students who would be studying abroad at U.S.U. in the coming fall semester. The UGermany students helped mentor the U.S.U. students in their transition to Germany, with the expectation that the U.S.U. students would reciprocate. One student stated post-program, *“I will say our (UGermany) counterparts that are here now were really welcoming. They were really nice; they were the best part of the whole experience. They really tried their best to make us feel at home.”* The U.S.U. students found these connections beneficial and were happy to have an opportunity to make friends internationally.

About 56% of the general German population has conversational English,^[21] and the instructors for the UO lab taught the course in English. The program was originally advertised to have a German language course component, but it was canceled a few weeks before the program began. Many students made an effort to learn basic German, primarily through Duolingo™, which received mixed reviews. They prioritized beginning conversations in German instead of assuming that others would speak English. Though the course was in English, the students stated that they had to be more conscious of their communication style to make sure they were understood by their German classmates and instructors. They discussed learning from practicing technical communication with a language barrier. One student described how being conscious of his word choices reinforced his technical learning in a way that he took for granted in the United States: *“The biggest thing for me was just learning how to work through problems together when there’s a language barrier... I feel like since we had to go through and teach each other both like what each (technical term) meant, it put more emphasis on what we were doing in the lab itself.”* Students said they looked forward to applying this skill in their future work; the exchange course provided a unique learning opportunity. Students had enough support and opportunity for growth for them to be in the learning zone for communication skills.

Extracurricular Activities. The eight-week program in Germany had benefits for students’ adaptation to the culture and personal growth. Since there were several weeks where the class did not meet, students had time to adapt to the area and learn to navigate it. They spoke about developing independence specifically by learning to do day-to-day tasks in a new context, such as purchasing a SIM card and communicating in a different language. They contrasted the experience to living in the United States, where they felt comfortable and did not have to be as conscious of their own actions to complete regular tasks. An exemplar quote is, *“I think studying abroad is good to develop yourself and learn a lot more about yourself, just because you are constantly being exposed to new people, new languages, new cultures, new foods, and it takes you out of your safety zone. You no longer have your safety blanket. You really are just out in the world,*

constantly learning new things and new things about yourself, and that is essential just for your own development.” The students were impressed with their own ability to adapt and live independently from what was familiar.

Because the beginning part of the course was canceled, some students used the unexpected free time to travel in Germany and to other European countries. This opportunity led to cultural observations and self-reflection, which some connected back to engineering. A student who went to Amsterdam, for example, noted how the environmental consciousness in the city was shown by biking and electric cars. His goal was to have a career in automotive engineering, and he stated that this experience taught him the importance of focusing on the needs of engineering product users. Other students spoke about learning travel skills in general, such as navigating the train system. The inevitable changes in travel plans led to practicing flexibility. One student described learning when their schedule went awry, *“I would say ultimately, learning to go with the flow and not get discouraged by plans being messed up... being able to sit back, collect ourselves... because if we just sit here and complain about it nothing’s going to happen. So, I think learning to be flexible like that can really translate into everyday life.”*

Summary. Within the course, the students began the program in the comfort zone because little was required of them as labs were repeatedly delayed. Their research experiences were similarly placed because they were acting as laboratory assistants. Students experienced panic near the end of the course when they had to make up for the cancelled classes earlier. The time without classes enabled extracurricular learning, as the students had time to travel and adapt to the everyday experiences in Germany. By being in an exchange program, students also identified that their intercultural communication skills were improving.

UDenmark Student Experiences

Chemical Engineering Lab Skills. Students in the four-week UDenmark program agreed that the lab and report writing required about 40 hours per week of work. Several students said that it was the most intense academic experience they had encountered. The UO lab course was designed for students to apply their prior theoretical knowledge in lab-based experiments. Many students said that this was the first time they had worked with equipment that they had previously learned about in theory-based courses. A student described, *“This is my first time operating equipment of this size, and hands-on operating things that we learn about in the class, so that’s been the most valuable thing for me because I feel like now it gives me a lot more perspective on what I’ve been learning the past three years.”* The students gave positive feedback on the opportunity to use their prior learning in an authentic context. They found that the lab was

an appropriate level of difficulty for them to be in the learning zone as they advanced their chemical engineering skills. Although they initially experienced panic, students were able to enter the learning zone and grow in their organization and time management skills.

One student gave a specific example of learning about lab safety. They noticed the smell of ammonia in an absorption lab and checked the monitors and were able to solve an issue in the lab. They described future applications of their learning as, *“One thing that you don’t really learn in classes is the safety aspects of the stuff you’re dealing with, so that (experience) put that aspect kind of front and center... So, I feel like that would be something important that I could take back to the class to recognize the safety aspect of what we’re designing.”* Learning about safety measures abstractly is a different skill set than having to apply knowledge in a real lab situation. The student stated that the lab gave them an opportunity to consider safety in a new way that they planned to apply to their future career.

The students described a rapid learning curve with writing lab reports. There were specific requirements for reports, which were graded by a U.S.U. engineering professor who traveled with them. The students would receive grades and have a few days to correct mistakes. They estimated that they spent 12-20 hours working on the first report but less on the following assignments. The students were aware of the value of professional writing skills and were happy to improve their skills in that area. One student expressed that this skill was one of their main learning goals of the program, saying, *“All through high school and in college, my weakest point in my school career was writing. And I knew that in the professional field, there’s not a lot of just pure calculations. It’s writing a lot, coming up with reports, and spitting out data in a readable way... so I’m really hoping that coming out of this I’m a lot more confident in my writing ability on a technical level.”*

The students worked in teams of two U.S.U. students. They chose their partners, unlike the other two sites. Students spoke less about frustration with team members than in the U.S.U. site, although some students still expressed they were stretched to learn about team collaboration. Some said that they were glad to have the chance to do more group work compared to their typical courses at U.S.U. A dynamic that resulted from students choosing group members was the balance between their personal and professional relationships since they also lived in shared apartments with other U.S.U. students. One student discussed the impact of working with a lab partner who is also their roommate and friend, and what it had taught them about collaboration: *“The most important thing was communication with the people I was working with. So, my lab partner and I were living in the same hotel for four weeks, working just very stressful projects. And we also have very different work styles and*

different work paces too... so the most important experience I had was to work through that to successfully turn in work while managing myself and my partner working together as a team. That was easily the most important (and) the most difficult challenge I had to deal with." Both group members were able to improve their communication and they viewed the course as a success.

Cultural Interactions. The students primarily interacted with U.S.U. students in their course and during their extra-curricular time. They described learning from living in a new country and were taught by faculty and TAs who work at UDenmark. Some noted cultural differences based on comparisons to their day-to-day experiences in the United States. One student explained how a simple difference in grocery store offerings led to a reflection on their awareness of other cultures: *"The biggest learning curve for me personally was actually buying food at the grocery store... at an American grocery store, peanut butter is really common. You see a whole half an aisle for it. Here there's usually four or five jars in the store and it's not the same, so small differences but most of what I've learned has been, I think, an increased sense of humility or feeling small as a part of a bigger thing."*

Like the other two sites, the course and materials were in English. Beyond the university setting, students also could expect most Danish people to speak English. About 86% of Danish people speak English as a second language.^[21] Most of the students did not spend time learning Danish beyond basic phrases. Some of them reflected on improving their communication skills, especially in a technical context. This idea was emphasized more by the students in the UGermany track, but one student at UDenmark described the advances in communication skills from communicating with non-native English speakers: *"I've had to consider my word choice... and how clearly I enunciate way more than I did back in the States... so that the actual technical information can be very clear."* The students were in the comfort zone for communication, but they had occasional opportunities for learning.

Extracurricular Activities. In every site, the students had seen each other in class or were acquaintances since they are in the same chemical engineering cohort. This track had the most discussion of U.S.U. students spending time together and becoming friends. They were happy to have the chance to form deeper connections with their peers from U.S.U., especially after spending multiple semesters online because of COVID. Students highlighted the friendships formed as one of their favorite parts of the program. When asked what the greatest personal benefit of the program had been, one student answered, *"Honestly a lot of friendships, I found. Because like I said I didn't really talk to my classmates in class before, even though I've had them in the same classes for the past two years. But now we've gotten to know each other*

and now that we're all living in the main (dormitory), we will go out to the grocery store or go get food or something together." Though they were in the program with students from other US universities, they did not mention spending time with those students. Deepening bonds with their peers was an unanticipated benefit for the students in this track.

UDenmark planned a group trip to northern Denmark for the students. There was an incident during that trip where a student said that they met a store employee who used terminology that is considered problematic in the United States. One student recounted that incident, expressing a balance between discouraging harmful words but also having cultural humility. *"I think it would be unfair to expect that standards hold up in the country across the ocean. But at the same time, it's something that you have to learn to manage and go, okay, I'm not expecting them to be on my same level of communication or say the exact same things as me, but I also have to hold a standard (that) this is not okay if it is problematic."* There was a common theme of cultural humility as students learned to interact in Denmark as outsiders.

Since the program's schedule was so intensive, students did not have time to travel during the four-week course. The students who were able to travel before or after expressed a similar development of travel skills to the students in the UGermany program. One student said they would also apply this experience to future business trips, explaining that they had learned the following: *"You need to be able to adapt to the environment that you're in and move quickly, the trains and the taxis, and you have to understand how to ask locals questions when you might not know the language. So, you have to be considering your surroundings at all points but that's for any part in the world."*

Overall, the students were in their comfort zone for most travel since they took trips as a group. When asked if they had learned about global engineering thus far in the program, one student stated, *"I would say that since it's an intensive four-week program, it's very packed in and we are definitely doing a high amount of work in the short amount of time. So, it kind of seems like (the instructors) are just wanting to present: Here's the program, here's what you need to do, here's the first two days, hit the ground running. So, I think that might play into why (global engineering) is not really much of a focus in this program right now."* The intense schedule seemed to be leaving the students less time to reflect on cultural differences.

Summary. The students at UDenmark had positive feedback about stretching prior skills in the laboratory course. They expressed that they were in the learning zone when using the equipment, application of theoretical knowledge, lab safety, technical writing, and time management. Their learning was aided by the evenly paced labs that had appropriate openness and high quality equipment. The students did not experience any permanent panic that did not eventually

turn into learning. Extracurricularly, students were more often in their comfort zone since they were part of a large cohort of U.S.U. students taking the course together. They had less time to travel independently because of the program length and intensity. They experienced some learning from the cross-cultural interactions that were available to them in planned group trips and from learning from the non-native English speakers teaching the course.

DISCUSSION AND CONCLUSIONS

The multiple course modalities for the UO Lab at this US university offered a unique opportunity to explore the potential benefits of study abroad by comparing with a similar technical lab course taken back home, and also by contrasting two study abroad arrangements. To analyze students' experiences, we used a modified version of the ZPD^[12,13] to identify whether students were in comfort, learning, or panic zones. In the learning zone, the students can develop new competencies but feel adequately supported. In the panic zone, students are expected to perform so far beyond their existing skills they become unmotivated, whereas students do not experience new opportunities in the comfort zone.

In the first part of our analysis, we looked at chemical engineering skill development. All three cases offered opportunities for students to learn. However, only at the UDenmark site, which was tightly run by one U.S.U. instructor dedicated to this role over the four weeks, were students kept steadily in the learning zone without panic. At the U.S.U. site by contrast, the course had multiple instructors and TAs, and there was inconsistency in how each approached the task of supporting the students. Some equipment was not functional, and so students were provided with data, thus not providing the full experience of designing and running an experiment. Students were combined in self-chosen pairs into groups of four, and many found the group experience further confounded the experience of panic. The UGermany site also showed experiences both in the learning and panic zones (beyond the first period of comfort while the course had not started yet), with panic resulting mainly from the compressed deliverables at the end because of this rescheduling. The group assignments (groups of three, some with a German student) were not reported as challenging, but some of these labs also had equipment failure as reported at U.S.U.

One distinction between the courses that is worth noting is that the U.S.U. course was valued at five credits and graded with an A-F scale. The courses abroad were pass-fail, and this difference did impact students' GPAs. They were counted as fewer credit hours and required an additional abbreviated lab course in the fall semester. For both of the courses abroad, students generally gave two types of responses when asked if the grading structure impacted their course selection. Some students stated that previous students

reported receiving high grades, so they were confident that the U.S.U. version would have raised their GPA. Others said that the pass-fail structure was not critical in their decision, but it was a bonus to have less pressure associated with the grading scheme. The A-F grading in the U.S.U. course may have led to more pressure for high performance, leading to additional conflict when some students wanted to expend minimum effort. In UDenmark the professor's feedback for the first lab surprised many students and led to them taking subsequent lab reports more seriously and working harder. With the inconvenience of the additional fall lab course, it did not appear to us that the students chose to study abroad in search of an easier academic path. More likely, there were intrinsic reasons for this choice. Our project's scope did not involve discussing the students' learning in the fall lab course. Regarding the next two categories of extracurricular experiences and cultural interactions, not surprisingly these did not yield learning for the U.S.U. students. For the UGermany students, there was tremendous learning in these domains, with students having more independent travel and a need to interact with UGermany instructors and students even in the course. These findings align with prior work's discussion of the stressors and benefits of working in cross-cultural engineering teams with a language barrier.^[11] For the UDenmark students, there was some evidence of the learning zone in cultural interactions, but less than the UGermany students because the overall study abroad was more managed by the U.S.U. instructor.

In summary, this study demonstrates the significant potential for a technical lab course integrated with a study abroad element to build technical skills as well as intercultural skills that are needed by engineering graduates.^[7] Global learning was described as most significant in the setting where the students took a course at the international partner university along with students from the home university, which appeared to offer a nice blend of familiarity, structure, and new learning opportunities. In making decisions on how to structure study abroad, this case study shows that there might be tradeoffs in opting for a more controlled study abroad where the course is run by an instructor from the home university while located abroad: students viewed that they were having more significant cultural learning in the UGermany setting, but they also had more experiences in the panic zone. These will be important design questions for program leaders to consider, especially when trying to incorporate global competencies into short-term programs, which prior research has shown to be difficult.^[6] When planning programs such as these, organizers should choose which learning outcomes to prioritize and balance stretch and support in student experiences related to that outcome to encourage engineering students to be globally competent.

Domestic courses can implement the best practices that were observed across courses, which included equally pacing the labs throughout the course, providing thorough

feedback, and establishing clear communication of expectations. Students highly valued professional development opportunities, specifically citing writing, research, open-ended lab design, and multitasking skills. In all iterations, students learned from opportunities out of their comfort zone when they have enough support to prevent panic.

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