

CROSS-CULTURAL LEARNING IN ENGINEERING EDUCATION: A BINATIONAL CASE STUDY ON INTERCULTURAL COMPETENCE AND SUSTAINABLE POLYMER PROCESSING

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ABSTRACT

This paper presents educational outcomes from a binational case study involving Baden-Wuerttemberg Cooperative State University (DHBW Loerrach), Germany, and Universidad Politécnica de Querétaro (UPQ), Mexico. Six engineering undergraduates – three per institution – collaborated for approximately one year to optimise the processing of recycled polypropylene, guided by one professor from each institution. The project followed a hybrid model combining two intensive two-week residential phases (one at each partner institution) with extended digital collaboration via MS Teams, WhatsApp and email. Roles including project management, material analysis, production, simulation, experimental design and design tasks were deliberately distributed to create clear responsibilities. A post-project questionnaire (n = 6) captured student perceptions using Likert-scale and open-ended items. Given the small cohort, findings are interpreted as illustrative case evidence rather than statistically generalisable results. Students rated the face-to-face phases as highly helpful (mean 4.83/5) and hands-on experimental activities as equally valuable for understanding sustainable engineering (mean 4.83/5). Digital collaboration received more mixed feedback (mean 3.67/5), with open responses citing time-zone coordination and differing work rhythms as key challenges. Students reported substantial self-assessed gains in intercultural communication (mean 4.33/5) and awareness of cultural diversity in engineering practice (mean 4.67/5). Faculty reflections highlight the value of early alignment sessions and stricter work-package definitions for future iterations. This case study demonstrates how binational hybrid projects can make diversity a lived experience within engineering curricula, offering a replicable framework for sustainability-oriented, cross-cultural education.

Keywords: Engineering education, intercultural learning, project-based learning, digital collaboration, polymer recycling

1 INTRODUCTION

Engineering and product design education are increasingly expected to prepare graduates for work in culturally diverse, globally distributed teams tackling complex sustainability challenges. At the same time, educators seek formats that integrate authentic research experiences, digital collaboration, and explicit attention to equality, diversity and inclusion within already dense curricula.

Polymer recycling provides a concrete and industrially relevant context in which such demands intersect: engineers must optimise materials and processes under real-world constraints while considering environmental impact and circular-economy principles. Working with recycled polypropylene, in particular, exposes students to trade-offs between mechanical performance, processing parameters, and resource efficiency that are central to sustainable product and process design. Against this backdrop, a binational project was established between Baden-Wuerttemberg Cooperative State University (DHBW Loerrach) in Germany and Universidad Politécnica de Querétaro (UPQ) in Mexico, bringing together three German and three Mexican engineering students. The primary project goal was to address a research question in the field of polymer recycling by collaboratively optimising the processing of recycled polypropylene, supported by one supervising professor at each partner institution.

The project was designed as a long-term, hybrid learning experience spanning approximately one year, with the majority of collaboration taking place online and two intensive two-week face-to-face phases

hosted in Mexico and Germany. Within the student team, roles such as project management, material analysis, production, simulation, experimental design, and design-related tasks were deliberately distributed to ensure clear responsibilities and to mirror professional engineering practice in distributed project teams.

This paper reports on the educational outcomes of this binational project, with a particular focus on students' development of intercultural communication and collaboration skills, their understanding of sustainability and research methodology in polymer engineering, and their experiences with digital teamwork. Drawing on post-project questionnaire data from the six student participants and faculty reflections, the paper discusses how the project design supported or hindered these learning goals and reflects on implications for integrating similar cross-cultural, sustainability-oriented projects into engineering and product design curricula.

2 CONTEXT AND RELATED WORK

Project- and problem-based learning (PBL) has become a central pedagogical approach in engineering higher education, because it engages students in authentic design and research tasks and supports the development of teamwork, problem-solving and communication skills [1, 2]. Recent reviews of PBL in engineering underline that such formats are particularly powerful when they address complex, real-world challenges related to sustainability, international collaboration and professional practice [1]. International project-based courses in engineering further show that working in diverse, geographically distributed teams can deepen students' technical understanding while simultaneously fostering project management skills and confidence in global collaboration settings [3].

In parallel, universities increasingly emphasise the development of intercultural competence and global citizenship as explicit learning outcomes, using virtual exchange, global virtual teams and other online collaboration formats [4]. Studies on international or cross-cultural online projects report that carefully designed virtual teamwork, combined with guided reflection, can significantly improve students' intercultural awareness, attitudes towards diversity and readiness to work in multicultural engineering environments [4]. Research-based learning initiatives in industrial and engineering project management additionally highlight that involving students in authentic research questions strengthens their understanding of methodology, data analysis and the research–practice interface, especially when projects are embedded in real organisational or industrial contexts [5]. The binational recycled-polypropylene project discussed in this paper builds on these strands by combining PBL, international and intercultural teamwork, virtual collaboration and research-based learning around a concrete sustainability challenge in polymer recycling.

3 PROJECT DESIGN AND METHODOLOGY

The project was implemented as a binational collaboration between Baden-Wuerttemberg Cooperative State University Loerrach (DHBW Loerrach), Germany, and Universidad Politécnica de Querétaro (UPQ), Mexico. Six engineering undergraduate students participated, three from each institution, studying in fields such as mechanical engineering, mechatronics and advanced manufacturing. The technical focus of the project was the optimisation of processing conditions for recycled polypropylene in order to investigate how process parameters influence mechanical performance in a sustainability-oriented polymer recycling context.

The project spanned approximately one year and was designed as a hybrid learning experience with two intensive face-to-face phases and an extended online collaboration phase. One two-week residential phase was hosted at UPQ in Mexico and one two-week phase at DHBW Loerrach in Germany, providing opportunities for joint laboratory work, planning sessions and intercultural exchange. The intervening months were characterised by predominantly digital collaboration, using tools such as Microsoft Teams, WhatsApp and email for coordination, document sharing and synchronous or asynchronous meetings.

The overall structure of the binational hybrid project, including the two face-to-face phases and the extended online collaboration, is summarised in Figure 1.

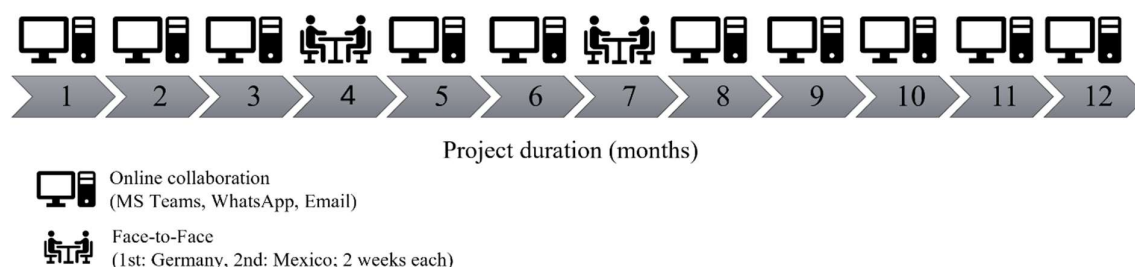


Figure 1. Overview of the hybrid binational project design

Within the student team, roles were deliberately distributed to mirror typical responsibilities in an industrial engineering project. Students took on functions such as overall project management, material characterisation, production and processing, simulation, experimental design and design-related tasks. This role allocation was intended to create clear lines of responsibility, foster ownership of sub-tasks and require students to coordinate their work across disciplinary and cultural boundaries. The project was jointly supervised by one professor at DHBW and one professor at UPQ, who provided guidance on both the technical polymer-engineering aspects and the collaborative processes.

To investigate the educational outcomes of this binational project, a small-scale case-study design was adopted. At the end of the project, a post-project questionnaire was administered to all participants in order to capture their perceptions of the project structure, their learning outcomes and their experiences of intercultural and digital collaboration. The survey consisted of Likert-type items using a five-point scale, covering the helpfulness of the face-to-face phases, the effectiveness of the digital collaboration phase, the clarity of research goals and experimental procedures, the usefulness of hands-on experimental and data-analysis activities, and perceived gains in intercultural communication, awareness of cultural diversity and preparedness for future sustainable engineering projects. In addition, open-ended questions invited students to describe main challenges in coordinating the project across countries and time zones, as well as key insights regarding research methodology and sustainability engineering. A potential source of response bias should be noted: as student participation and travel were financially supported by the Baden-Württemberg Stiftung, participants may have felt reluctant to provide critical feedback. The questionnaire was anonymous and voluntary, and open-ended items actively invited critique; nonetheless, this limitation should be kept in mind when interpreting the results. Quantitative items were analysed descriptively, calculating frequencies, means and standard deviations for each Likert-scale question. Qualitative responses were read repeatedly and coded inductively to identify recurring themes related to collaboration challenges, perceived benefits of the hybrid structure and students' reflections on research methodology and sustainability. The combination of descriptive statistics and thematic analysis provided a basis for interpreting how the project design supported or constrained the intended learning outcomes.

4 RESULTS

The post-project questionnaire yielded six responses from the student participants. Given the small cohort size, all findings are interpreted as case evidence only and do not support statistical generalisation. Overall, students rated the hybrid binational project very positively, particularly with regard to the intensive face-to-face phases at UPQ in Mexico and at DHBW Loerrach in Germany and the hands-on experimental work on recycled polypropylene.

Figure 2 summarises ratings for the main Likert-type items (five-point scale, 1 = very low, 5 = very high).

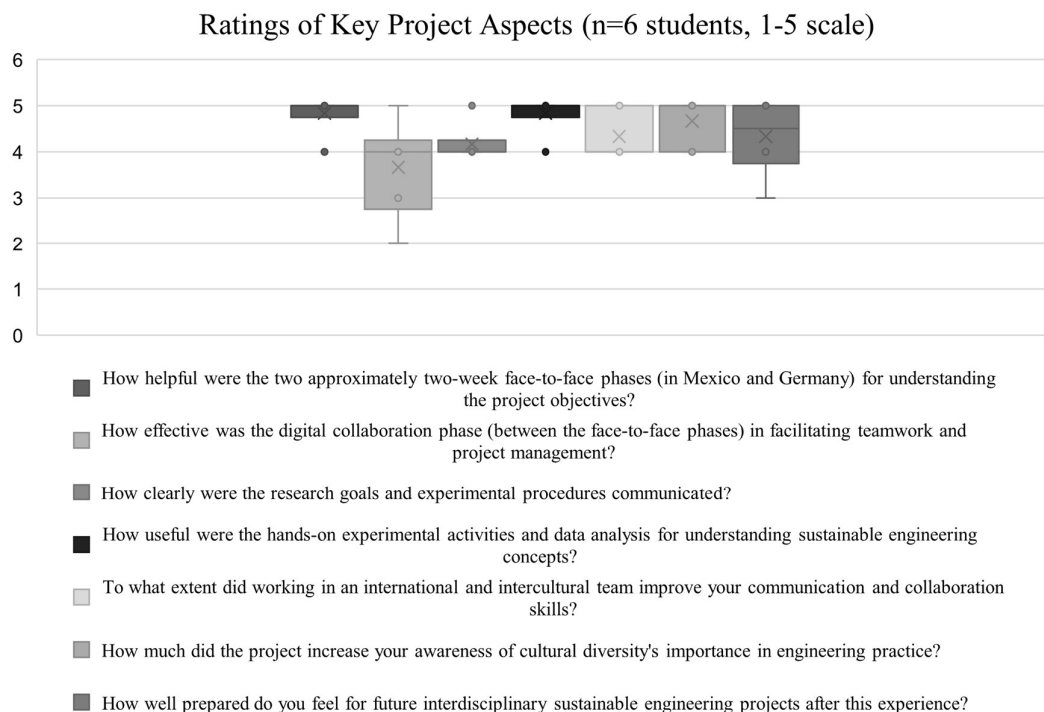


Figure 2. Descriptive statistics for key survey items (students only, five-point scale)

Students perceived the two approximately two-week face-to-face phases in Mexico and Germany as extremely helpful for understanding the project objectives (mean 4.83, range 4–5) and rated the hands-on experimental activities and data analysis as equally valuable for understanding sustainable engineering concepts (mean 4.83, range 4–5). Perceived clarity of the research goals and experimental procedures was also high (mean 4.17, range 4–5).

In contrast, experiences with the digital collaboration phase were more mixed. The mean rating of 3.67 (range 2–5) corresponds to a medium effect size relative to the neutral midpoint, suggesting that students overall saw online collaboration as somewhat effective, but with substantial variation between individuals. Open-ended responses highlight typical challenges of distributed collaboration, such as scheduling meetings across time zones, aligning different course loads and work rhythms, and perceived differences in reliability or work ethic between partners.

At the same time, students reported substantial perceived gains in intercultural and sustainability-related competencies. Based on the post-project survey, participants reported self-assessed improvements of approximately 36% in intercultural communication, 28% in confidence in scientific communication, and 33% in understanding of sustainability. These global gains are consistent with the high end-of-project ratings for items on intercultural communication and collaboration (mean 4.33, range 4–5), increased awareness of cultural diversity in engineering practice (mean 4.67, range 4–5), and preparation for future interdisciplinary sustainable engineering projects (mean 4.33, range 3–5).

Qualitative answers further illustrate these developments. Several students explicitly mentioned the Design of Experiments (DoE) approach as a powerful tool for planning and interpreting the experiments on recycled polypropylene and noted that working with real process parameters and material data deepened their understanding of how processing conditions influence mechanical behaviour and sustainability trade-offs. One student remarked that “seeing the actual material change under different settings made sustainability feel real, not just theoretical.” Others emphasised that collaborating in a mixed DHBW–UPQ team made cultural differences in communication styles, expectations and reliability visible, but also helped them to develop concrete strategies for addressing such challenges, such as clearer role definitions, a single central communication channel, and earlier in-person alignment. A recurring theme in open responses was the value of the residential phases as relationship-building moments: students noted that trust established face-to-face made subsequent online work considerably

smoother. From the faculty perspective, both supervising professors observed that the deliberate role distribution helped to maintain student ownership and momentum throughout the year-long collaboration. The DHBW supervisor noted the importance of establishing shared expectations for communication frequency and documentation standards during the first residential phase, while the UPQ supervisor highlighted that the mixed-discipline team composition – spanning mechanical engineering, mechatronics and advanced manufacturing – required explicit guidance on integrating diverse technical viewpoints. Together, the quantitative and qualitative findings suggest that the project effectively combined technical learning about polymer recycling with research-methods training and the development of intercultural collaboration skills in a realistic hybrid project setting.

5 DISCUSSION AND IMPLICATIONS

The findings from this binational hybrid project align with prior work on project-based learning (PBL) in engineering education, which consistently shows that authentic, hands-on tasks in real-world contexts foster deep understanding of technical concepts and research methodologies [1, 2]. The very high ratings for the usefulness of experimental activities and data analysis in understanding sustainable engineering concepts (mean 4.83) underscore how working with actual recycled polypropylene and process parameters made abstract sustainability principles tangible. These technical results, including the optimisation of mechanical properties through process-parameter variation, were published at IEEE TEMSCON Global 2025 [6]. Similarly, the strong perceived helpfulness of the two face-to-face phases (mean 4.83) confirms that intensive residential blocks provide critical opportunities for laboratory work, planning and relationship-building that cannot easily be replicated online [3].

The more mixed ratings for digital collaboration (mean 3.67), however, echo findings from global virtual team (GVT) and virtual exchange studies, which frequently report challenges with time-zone coordination, scheduling, and perceived differences in work rhythms and reliability [4, 5]. The qualitative responses mentioning meeting schedules and work-ethic differences illustrate these dynamics in a concrete engineering context. It is also important to acknowledge that students whose travel and participation were financially supported may have felt inclined to give more favourable feedback. While the open-ended items and anonymised format were designed to mitigate this, future iterations should consider independent evaluation approaches. At the same time, the high intercultural competence gains (mean 4.33) and increased diversity awareness (mean 4.67) suggest that the deliberate role distribution, joint supervision and structured hybrid format provided sufficient scaffolding to turn these challenges into learning opportunities.

These results have several implications for designing cross-cultural, sustainability-oriented projects in engineering and product design education. First, hybrid formats combining short intensive residential phases with extended online collaboration appear particularly effective for simulating distributed engineering practice while mitigating some limitations of purely virtual work. Second, clear role allocation and joint faculty supervision across institutions emerge as critical enablers for small, binational student teams to maintain momentum and address intercultural challenges productively. Third, embedding authentic research tasks such as polymer process optimisation within such projects creates powerful opportunities to develop both technical sustainability expertise and methodological competencies alongside soft skills.

Future iterations of this project will incorporate student suggestions such as earlier face-to-face alignment, a central communication platform and stricter work-package definitions to further improve the digital collaboration experience. The model also holds potential for scaling to larger cohorts or adaptation to other sustainability challenges in materials engineering and product design, provided that institutional partnerships and funding support (such as the Baden-Wuerttemberg Stiftung) remain in place.

6 CONCLUSION AND REFLECTIONS

This paper has presented the educational outcomes of a binational hybrid project in which six engineering students from Germany and Mexico collaborated for approximately one year to address a research question in polymer recycling. The project design, combining two intensive face-to-face phases with extended online collaboration, successfully fostered high levels of student engagement with both the technical content and the intercultural teamwork process.

The survey results provide clear evidence that students perceived substantial learning gains across multiple dimensions. The face-to-face phases and hands-on experimental work on recycled

polypropylene received the highest ratings, confirming their value for understanding sustainable engineering concepts and research methodologies. Students also reported strong improvements in intercultural communication skills and awareness of cultural diversity's role in engineering practice, despite acknowledging challenges in the digital collaboration phase such as time-zone coordination and differing work rhythms.

These findings demonstrate that carefully structured binational projects can make diversity and internationalisation tangible within core engineering curricula, rather than treating them as peripheral add-ons. The deliberate role distribution, joint supervision across institutions and hybrid format proved effective in supporting small student teams to navigate both technical complexity and intercultural dynamics productively.

Reflections from the supervising faculty highlight several areas for refinement in future iterations. While the residential phases provided irreplaceable opportunities for laboratory work and relationship-building, the digital phase would benefit from earlier face-to-face alignment, stricter work-package definitions and a single central communication platform to reduce coordination friction. Assessment strategies could also be enhanced by incorporating more frequent progress check-ins and peer-evaluation components to maintain accountability in distributed teams.

Limitations of this study include the small sample size ($n = 6$) from a single project cohort, which precludes statistical generalisation. The study is best understood as a case example highlighting lessons learned. Potential response bias due to funded participation is acknowledged. Future work will involve replicating the model with larger groups, incorporating independent evaluation methods, exploring longitudinal effects on students' career trajectories, and adapting the approach to other sustainability challenges in materials engineering and product design. Three key takeaways emerge for educators considering similar binational projects: first, a two-phase residential structure is highly effective for establishing trust and shared working norms before transitioning to extended online collaboration; second, clear role allocation from the outset, agreed jointly by faculty at both institutions, is essential for maintaining accountability and momentum in small distributed teams; and third, embedding an authentic technical research question creates synergy between sustainability learning, research-methods training and intercultural competence development, making all three goals mutually reinforcing rather than competing. The project thus offers a replicable framework for engineering educators seeking to integrate sustainability research, intercultural competence and digital collaboration into their curricula, with diversity becoming a lived experience rather than an abstract curriculum objective.

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