

Mathematics Across Borders: the Impact of a Linear Algebra COIL Project on Students' Cultural Intelligence

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How to cite: Barana, A.; Boetti, G.; Marchisio Conte, M.; Perrotta, A.; Sacchet, M. (2026). Mathematics Across Borders: the Impact of a Linear Algebra COIL Project on Students' Cultural Intelligence. In: 12th International Conference on Higher Education Advances (HEAd'26). Valencia, 15-18 June 2026. <https://doi.org/10.4995/HEAd26.2026.21785>

Abstract

This study investigates the development of intercultural competence through a Collaborative Online International Learning (COIL) project focused on Linear Algebra, involving undergraduate students from University College Dublin and the University of Turin. The research aims to identify which dimensions of Cultural Intelligence are impacted by these mathematical activities and whether different Mathematics educational backgrounds, based on the country's schooling system, influence students' Cultural Intelligence. Qualitative analysis of student reflections and statistical testing reveal that nearly all participants gained significant levels of cultural knowledge, while cross-cultural skills and cultural metacognition emerged less frequently. No statistically significant differences were found between institutions, indicating that the COIL experience had a positive impact regardless of the national curricula or the specific mathematical cultural backgrounds of the participants. The study concludes that short-term COIL interventions can foster foundational development in Cultural Intelligence, providing a necessary basis for the development of intercultural sensitivity.

Keywords: COIL, cultural intelligence, intercultural competence, mathematics education

1. Introduction

Globalisation is reshaping society, requiring Higher Education Institutions (HEIs) to embrace internationalisation (De Wit et al., 2015). To navigate this dynamically changing, multicultural, and digital society, students, as world citizens, require a broader set of competences, including intercultural competence and soft skills, such as team collaboration, communication and presentation skills, problem solving, critical thinking, and responsibility. HEIs empower

students to develop these skills by offering access to international academic experiences such as Collaborative Online International Learning (COIL) activities, which constitute immersive environments that foster international collaboration and expose learners to a wealth of diverse academic perspectives.

Learning Mathematics can be considered as a form of intercultural learning, as Mathematics is a culture of formal thinking (Prediger, 2001). From this perspective, engaging in mathematical activities in international contexts offers more than just cognitive benefits; it also fosters the ability to navigate overlapping cultural environments, where students' everyday cultural orientations intersect with the culture of Mathematics (Prediger, 2001). Accordingly, international mathematical initiatives, such as those delivered through COIL activities, can provide authentic opportunities for students to engage with cultural diversity not only at the social level but also in relation to different approaches to reasoning and problem-solving.

In this paper, we analyse a COIL experience co-designed and co-delivered by the University College Dublin (UCD, Ireland) and the University of Turin (UniTo, Italy) in November 2024 (Barana et al., 2025b). The COIL project, entitled “Linear Algebra for Economic, Finance, Security and Defence strategies” (LAEFSD), involved 10 hours of activities in which students were organised into international teams and worked on mathematical tasks involving linear algebra applied to security, defence, and economics contexts. The current study aims to explore the development of intercultural competence in relation to factors of Cultural Intelligence (CQ), with specific attention to an educational international context centred on Mathematics, which is a discipline often perceived as critical and challenging for students but essential in the area of security and defence (Marchisio Conte et al., 2025) and economics (Nikoloudakis & Choustoulakis, 2019). Within this context, collaboration goes beyond being a useful learning strategy and may be necessary, given the diversity of backgrounds and perspectives that participants bring to international activities.

2. Theoretical framework

To boost internationalisation, many HEIs leverage physical student mobility. However, empirical data indicate a significant mobility gap, with only 10%-13% of undergraduates in Europe and the US participating in these programs (European Commission and European Education and Culture Executive Agency, 2020; Institute of International Education, 2024). This low participation rate, which may be determined by socio-economic and personal barriers, suggests that traditional models of mobility may be inherently non-inclusive, precluding to some students the opportunity to develop the intercultural and transversal skills now required by contemporary society. To overcome this situation, innovative, more inclusive and environmentally sustainable collaborative mobility methods are increasingly being proposed and implemented. COIL activities can be classified as a type of international virtual

collaboration, as they are fully delivered online through digital technologies to support collaborative projects undertaken by students at their home institutions. Since they are not typically credit-bearing and do not require specific funding, COIL activities minimise bureaucratic hurdles and simplify institutional approval processes. Based on established best practices, COIL is characterised by the cross-border collaboration of educators who co-design and co-deliver curricula or specific tasks with unified learning outcomes (Rubin & Guth, 2023). As stated by Hackett (2024) and colleagues, who proposed a formal definition of COIL, COIL activities, which typically span four weeks to a full semester, can foster the development of intercultural competence, as they require collaborating in an international and multicultural context. Intercultural competence (Deardorff, 2006) is fundamentally characterised by the relational dimension of human interaction and constitutes a dynamic, longitudinal process through which individuals cultivate greater cultural sensitivity. According to Deardorff (2006), intercultural competence should be viewed as a continuous developmental process rather than a discrete outcome of a single event, such as studying abroad. In higher education, international initiatives like COIL serve as effective catalysts for intercultural communication and openness to diverse cultures, provided that the collaborative design is intentionally structured to facilitate meaningful engagement (Barana, et al., 2025c; De Hei et al., 2020). In academic literature, intercultural competence is often operationalised through two primary and interconnected aspects: multicultural effectiveness (Van Der Zee & Van Oudenhoven, 2000) and CQ (Thomas et al., 2015). Particularly, Thomas et al. (2015) define CQ as “a system consisting of cultural knowledge, cross-cultural skills, and cultural metacognition that allows people to interact effectively across cultures”. As described by Thomas et al. (2015), cultural knowledge encompasses both content-specific insights into the internal logic of diverse cultures and general process knowledge gained through experience, which enhances cognitive complexity and allows individuals to navigate new cultural terrain. According to Thomas et al. (2015), this foundational knowledge is operationalised through cross-cultural skills, a broad set of competencies including relational ability, tolerance for uncertainty, adaptability, empathy, and perceptual acuity, all of which are essential for adjusting behaviour to fit specific social contexts. Finally, cultural metacognition serves as the regulatory mechanism of the construct, involving the deliberate monitoring and analysis of cultural contexts to plan and execute appropriate courses of action. Together, these components form a comprehensive framework for assessing an individual's capacity to function effectively across diverse environments.

3. Research context and methodology

In the current study, we want to investigate the impact of an international Mathematics activity on the dimensions of CQ (Thomas et al., 2015). Specifically, we consider the COIL project LAEFSD, which was co-designed by UCD and UniTo, following the INVITE Learning Design Framework (Barana et al., 2025d). This 10-hour extracurricular initiative, implemented as a

pilot edition in November 2024, involved 32 first-year students, specifically 20 from the BSc in Economy & Finance and from the BSc in Financial and Actuarial studies attending the MATH10120 linear algebra module at UCD and 12 from the BSc Strategic and Security Sciences at UniTo attending the CPS0977 Mathematics module, thus learners had different backgrounds, cultures and skills. Students were organised in international teams and were required to collaborate virtually. Students completed an initial ice-breaking activity, two core tasks applying linear algebra to real-world scenarios – a cryptography problem and a macroeconomics policy problem – and a final group presentation. Collaboration was facilitated through web conferencing and a Learning Management System. Students were invited to use computational tools, such as Python, Maple, and Excel, to solve the tasks in Linear Algebra. The COIL formative evaluation was conducted via individual reflective diaries, surveys, and group presentations to measure mathematical, digital, and intercultural competence. Students participating to all the activities, and submitting all the deliverables, received a certificate of participation, co-signed by the two institutions. In this context, the research study has been guided by the following research questions: (RQ1) Which dimensions of Cultural Intelligence are impacted by a Collaborative Online International Learning (COIL) activity in Mathematics in Higher Education? (RQ2) Are there significant differences in frequencies of the dimensions of CQ based on the students' Mathematics educational backgrounds, depending on the country's schooling system?

For the analysis, we considered students' responses to the final survey. Of the 32 original participants, four responses are missing: two students could not attend all activities due to personal commitments, and two did not complete the final questionnaire, resulting in 28 responses (19 from UCD and 9 from UniTo). As this was a pilot edition, a specific ad hoc questionnaire to measure the dimensions of CQ had not yet been implemented. Consequently, for the analysis, we selected the students' responses to the following open-ended questions: (1) What activities did you carry out? Indicate shortly the goal, your role, and your main contribution and accomplishment. Be specific. (2) What was accomplished by your team? (3) How did you take advantage of the international interaction and collaboration with peer students from different countries? (4) How did the experience change your thinking of the country or the people from the country you were working with, or the topics/issues you discussed? Any surprise?

For each student, the responses to the four questions were combined into a single text, which was used as the unit of analysis. They were independently reviewed by two researchers to identify evidence of the different CQ dimensions emerging from the students' reflections, and not only from mere textual mentions. Thomas et al.'s (2015) definitions of CQ dimensions were used as descriptors for coding the responses. Each dimension was assessed independently to determine whether the responses demonstrated an actual development of that specific factor. Any discrepancies were subsequently discussed between the researchers to reach a consensus

on the dimensions identified: cultural knowledge, cross-cultural skills, and cultural metacognition. After calculating the frequencies for each dimension, Fisher's exact tests were performed to determine if significant differences existed across the dimensions depending on the students' home institutions, specifically UCD and UniTo, thus on their cultural and mathematical background.

4. Results and discussion

Table 1 presents the frequencies of the CQ dimensions identified by the researchers in the students' responses, distinguishing between UCD and UniTo students.

Table 1. Frequencies of the dimensions of Cultural Intelligence.

	Answers analysed	Cultural Knowledge	Cross-cultural Skills	Cultural Metacognition
UCD	19	18	5	6
UniTo	9	9	6	3
Total	28	27	11	9

The findings reveal that nearly all participants (27 out of 28) attained cultural knowledge, and so an understanding of different cultures. For the student whose cultural knowledge did not emerge in his/her written answers, even though the specific dimension was not formally coded in his/her response, his/her descriptions of positive interactions and successful collaborations with peers from diverse backgrounds suggest that he/she has internalised this knowledge, even if he/she did not explicitly articulate it in answering the survey. Regarding cross-cultural skills, the data shows a total of 11 occurrences, indicating that the ability to adapt behaviour and relate successfully to culturally different others does not emerge in students' answers. A similar trend with 9 occurrences is observed for cultural metacognition, which involves the conscious monitoring and purposeful regulation of mental and emotional states to achieve specific objectives. These results are reasonable for two main reasons. Firstly, the COIL activities comprise approximately 10 hours (including plenary activities and independent group work) spread over a month. However, factors such as cross-cultural skills and cultural metacognition have a more significant long-term effect (Barana et al., 2025a; Hackett et al., 2023). Secondly, the responses analysed were to open-ended questions that did not specifically prompt students to reflect on CQ dimensions but rather encouraged them to reflect generally on their COIL experience.

We then created contingency tables and performed statistical tests to verify whether there were differences between students depending on their institution for each dimension of CQ. Due to the small sample size and the presence of cells with fewer than five counts, we used Fisher's exact test. The results obtained are not statistically significant, as p-values exceed 0.05,

specifically $p = 1$ for cultural knowledge and cultural metacognition, and $p = 0.095$ for cross-cultural skills, so we fail to reject the null hypothesis. The lack of statistically significant differences across institutions may suggest that the COIL environment served as a common denominator for intercultural growth. This result indicates that the COIL methodology has effectively transcended institutional boundaries, ensuring that all students, despite potential differences in their national curricula and social backgrounds, developed comparable levels of CQ. In this sense, the COIL programme has helped ensure that international collaboration is effective and promotes the development of intercultural skills more broadly. It is noteworthy that the mathematical component of the project acted as a significant catalyst for the development of CQ. The qualitative data revealed that students actively engaged with the differences of teaching Mathematics in the two countries: the highly practical, application-oriented approach typical of the Irish system and the more formal, theoretical framework characteristic of the Italian tradition. For instance, an Italian student noted: *“our studies are much more theoretical than those of our Irish colleagues”*. An Irish student observed that *“it was interesting how the Italian approach is more theoretical while I have always preferred to work with solid numbers. Therefore I think that the greatest thing I took from COIL was to see how the Irish way of thinking isn’t the only way.”* Rather than experiencing these differences as a barrier, students demonstrated a remarkable ability to synthesize both methodologies to tackle complex mathematical problem-solving tasks. This cognitive flexibility is reflected in the final questionnaire, where several participants highlighted how the mathematical challenge forced them to negotiate different ways of thinking, as highlighted in the following sentence written by a participant: *“I found that working with someone from another country gave me a different perspective on how to approach problems and gave me another outlook on other cultural points.”* Ultimately, this successful integration of diverse academic cultures not only led to the achievement of mathematical objectives but also fostered key transversal competencies and intercultural sensitivity.

5. Conclusion

This research focused on investigating the CQ development in the pilot edition of the COIL project LAEFSD that was co-designed and co-implemented by the UCD (Ireland) and the UniTo (Italy) in November 2024. Even if based on a small sample size, the results revealed that students took advantage of this experience in terms of the dimensions of the CQ also thanks to the exposure to different mathematical problem-solving approaches of their peers with different Mathematics educational backgrounds, based on the country's schooling system. It must be noted that participants' specific educational trajectories were not investigated, leaving their prior schooling locations (e.g., Italy, Ireland, or elsewhere) unverified and assuming they were in the country of their home institution. This represents a limit of this study that would be improved in future research. Although this COIL intervention was a short-term experience

lasting only one month, it nonetheless fostered significant development in CQ. As argued by Engle and Crowne (2014), even short international assignments can have a measurable impact on the dimensions of CQ. In this study, cultural knowledge emerged as the dimension most affected, a finding consistent with the project's limited duration. However, rather than being viewed as a final outcome, this experience should be regarded as a foundational 'seed': whilst the immediate gains were primarily cognitive, the intervention may have initiated a developmental process that provided the necessary foundation for future growth in the metacognitive, motivational, and behavioural dimensions of CQ. Furthermore, no differences were observed across institutions, indicating that the COIL experience effectively transcends differences in national curricula and social backgrounds, promoting the development of intercultural skills among all participants. Building upon these findings, future research will investigate the impact of the COIL experience on intercultural competence within the 2025 edition. We intend to use specially designed questionnaires to assess the various dimensions of intercultural competence, supplemented by a comparative analysis of recorded student group meetings to triangulate quantitative data with qualitative behavioural insights.

Acknowledgement

The research activity described in this paper has been carried out within the GNSAGA group of INDAM – “Istituto Nazionale di Alta Matematica Francesco Severi”. Part of the research of this publication is supported by a grant under the National Recovery and Resilience Plan (NRRP), D.M. 118/2023 by the Italian Ministry of University and Research (MUR), funded by the European Union–NextGenerationEU.

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Article in Press