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Benchmarking Cognitive and Professional Competency Attainment in Foundation Engineering: A Study on the Efficacy of Authentic Alternative Assessments

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Abstract

Outcome-Based Education (OBE) necessitates a systematic alignment between curriculum design, teaching–learning strategies, and assessment to ensure measurable learning attainment through continuous quality improvement (CQI). This study presents a longitudinal analysis of an undergraduate Foundation Engineering course, evaluating Course Learning Outcome (CLO) attainment across four academic cohorts from 2020 to 2023. By integrating modern geotechnical software and authentic alternative assessments, including software-based mini-projects, peer-evaluated teamwork, and technical reporting, the course moves beyond traditional examinations to capture complex analytical reasoning and professional competencies. To ensure objective evaluation, a robust methodology of statistical normalization (Normalised Attainment Index, NAI) and institutional threshold benchmarking ($NAI \geq 0.50$) was employed to mitigate cohort-scale bias and assessment variability. Results indicate that all CLOs consistently met or exceeded the institutional benchmark, demonstrating sustained outcome attainment across all years. While technical design competence (CLO1) exhibited controlled variability reflecting the high cognitive and judgment-based demands of authentic engineering problem-solving, professional competencies in communication (CLO3) and teamwork (CLO4) showed progressive stability through the implementation of structured rubrics. Beyond course-level evaluation, this study advances outcome-based education by demonstrating how normalised longitudinal benchmarking distinguishes learning complexity from instructional deficiency in design-intensive engineering contexts. The study introduces a triangulated mapping of CLOs, assessment modes, and Bloom's Taxonomy domains, providing a replicable framework for evidence-based CQI and accreditation-aligned curriculum review in design-intensive engineering education, while demonstrating how such frameworks can simultaneously foster technical excellence, digital literacy, and professional skills.

Keywords: Outcome-Based Education, Foundation Engineering, CLO Attainment, Geotechnical Curriculum, CQI, Alternative Assessment.

1 Introduction

Foundation Engineering serves as a critical specialization within civil engineering curriculum, requiring students to integrate complex soil mechanics theory with engineering judgment and foundation design principles under uncertain ground conditions. Within an Outcome-Based Education (OBE) framework, this complexity necessitates explicit alignment between learning outcomes, teaching strategies, and assessment mechanisms to ensure demonstrable student achievement (Biggs and Tang 2011; Spady, 1994). Beyond technical foundations, the course provides a platform for developing design competence, digital literacy, and professional communication skills (Bloom et al., 1956; Anderson and Krathwohl, 2001).

Despite mandatory accreditation requirements for CLO reporting, many studies rely on raw attainment scores, which limit meaningful longitudinal comparisons (Yusof et al., 2021). This paper addresses this limitation by examining multi-year CLO attainment through statistical normalisation, threshold benchmarking, and variability interpretation. The study contributes evidence-based insights into curriculum alignment and supports continuous quality improvement (CQI) in geotechnical education.

While the adoption of authentic and alternative assessments has increased, limited empirical work has examined how learning complexity in design-intensive engineering courses can be distinguished from instructional weakness across multiple cohorts. This study addresses this conceptual gap by reframing CLO variability as an indicator of epistemic demand rather than attainment failure.

The study utilizes a longitudinal approach across four academic cohorts (2020–2023) to operationalise this interpretive lens within an authentic assessment context. By integrating modern engineering tools and project-based learning (PBL), the curriculum is designed to capture analytical reasoning, teamwork dynamics, and professional communication beyond traditional final-answer performance. The primary contributions of this work include:

- The application of a replicable CLO benchmarking and evaluation framework for interpreting learning complexity that supports accreditation-aligned curriculum reviews;
- Evidence-based insights into Continuous Quality Improvement (CQI) through the analysis of learning complexity and assessment alignment.
- A demonstration of how authentic engineering problem-solving can be sustained and measured over time within an OBE-driven programme.

2 Course Context and Learning Outcomes

The Foundation Engineering course (KNS3243) is a 3-credit undergraduate requirement designed to bridge theoretical soil mechanics with practical geotechnical design. The curriculum covers critical domains including shallow and deep foundation design, foundations on difficult soils, ground improvement techniques, and the application of industry-standard geotechnical software. To ensure a holistic development of graduate attributes, the course is structured around four Course Learning Outcomes (CLOs) that span cognitive, psychomotor, and affective domains as presented in Table 1.

Table 1. Alignment of Course Learning Outcomes (CLOs) with Bloom's Taxonomy Action Verbs

CLO	CLO Description (Condensed)	Dominant Bloom's Domain	Bloom's Level(s)	Representative Action Verbs	Primary Assessment Evidence
CLO1	Design shallow and deep foundations under various ground conditions	Cognitive	Analyse, Evaluate, Create	analyse, compute, evaluate, design, justify	Final examination, analytical assignments
CLO2	Apply modern engineering tools in foundation design	Psychomotor / Cognitive	Apply, Analyse	model, simulate, apply, interpret, optimise	Software-based mini project
CLO3	Produce technical reports on foundation practice	Cognitive / Affective	Evaluate, Create	organise, synthesise, document, justify, present	Technical report
CLO4	Demonstrate teamwork and professional interaction	Affective	Respond, Value, Organise	collaborate, contribute, negotiate, reflect	Peer evaluation, group project

The CLOs reflect an established progression in design-intensive engineering education from analytical competence, to tool-mediated reasoning, to professional judgment and collaboration, mirroring the epistemic practices expected of entry-level geotechnical engineers. This progression ensures that learning outcomes capture not only procedural knowledge but also the integrative, judgment-based competencies required in professional engineering practice. Table 1 demonstrates that each CLO is intentionally articulated using measurable Bloom's taxonomy verbs aligned with its dominant learning domain. Design-oriented CLOs emphasise higher-order cognitive processes, while modern tool usage targets applied psychomotor skills. Communication and teamwork outcomes are aligned with affective-domain verbs, ensuring that professional

competencies are assessed through authentic, performance-based tasks. This explicit verb alignment enhances measurability, assessment validity, and accreditation compliance (Bloom et al., 1956; Anderson and Krathwohl, 2001).

3 Methodology

The research methodology employs a longitudinal, quantitative approach to evaluate learning outcome attainment, supported by qualitative mapping of assessment integrity. Data were collected from four academic cohorts (2020–2023) to assess the consistency and robustness of the Foundation Engineering curriculum.

3.1 Data Collection and Assessment Mapping

The study utilizes aggregated CLO indices derived from weighted assessment components tailored to the specific demands of geotechnical engineering. Each assessment is strategically mapped to ensure the triangulation of cognitive, psychomotor, and affective domains:

- **Analytical Design (CLO1):** Assessed through final examinations and design-oriented assignments.
- **Modern Tool Application (CLO2):** Evaluated via software-based mini-projects to ensure computational literacy.
- **Professional Reporting (CLO3):** Measured through a structured technical report focusing on synthesis and recommendation.
- **Collaborative Practice (CLO4):** Assessed using peer evaluation rubrics to capture teamwork dynamics.

The dataset comprises aggregated CLO attainment results from four academic cohorts (2020–2023), representing the full enrolment of students in the Foundation Engineering course for each respective year. Each cohort reflects typical class sizes for the programme, ensuring that the analysis captures representative trends in student performance across multiple academic cycles.

3.2 Statistical Normalisation

CLO attainment data from four academic cohorts (2020–2023) were analysed using aggregated indices derived from weighted assessment components. To enable fair longitudinal comparison across cohorts and mitigate variations in assessment scale, a max-based normalisation approach was applied (Felder and Brent, 2004). This approach preserves relative performance trends by anchoring attainment to the highest observed value for each CLO, thereby reducing cohort-specific bias while maintaining sensitivity to differences in learning complexity. The Normalised Attainment Index (NAI) is calculated as follows:

$$\text{Normalised Attainment Index (NAI)} = \frac{A_{CLO,i}}{\max(A_{CLO})}$$

where $A_{CLO,i}$ represent the raw attainment value for a specific CLO in year i , and $\max(A_{CLO})$ denotes the maximum recorded attainment for that CLO across all cohorts. This index ranges from 0 to 1, where 1.0 signifies the peak historical attainment.

The use of NAI enables consistent benchmarking of CLO performance across cohorts with differing sizes, assessment conditions, and grading distributions. By normalising attainment values, observed variability can be interpreted as reflecting differences in learning complexity rather than inconsistencies in assessment practice. Given the aggregated nature of the data and the study's focus on curriculum-level evaluation, a descriptive benchmarking approach is adopted in place of inferential statistical analysis. This ensures practical interpretability while aligning with Outcome-Based Education (OBE) and Continuous Quality Improvement (CQI) practices.

3.3 Attainment Threshold Benchmarking

In alignment with Outcome-Based Education (OBE) best practices, an institutional benchmark of $\geq 50\%$ (or NAI ≥ 0.50) was established (Sharma and Fidalgo-Blanco, 2022 and Spady, 1994). This threshold serves as the minimum acceptable level to indicate that a majority of students have satisfactorily achieved the intended learning outcomes.

For statistically normalised data, the benchmark corresponds to a Normalised Attainment Index (NAI) ≥ 0.50 , enabling direct comparison across cohorts while maintaining alignment with accreditation expectations.

3.4 Variability Interpretation

Rather than relying solely on statistical significance, variability was interpreted qualitatively based on dispersion patterns in the normalized trends. This approach allows for a pedagogical focus on "learning complexity," particularly in design-intensive areas where judgment-based reasoning is required.

4 Results and Analysis

The analysis of Course Learning Outcome (CLO) attainment for the Foundation Engineering course focuses on longitudinal trends across four academic cohorts (2020–2023). By utilizing statistical normalization and visual analytics, the study provides a transparent evaluation of student achievement and assessment reliability.

4.1 CLO Attainment Trends

The raw attainment data indicates that all CLOs consistently meet or exceed the institutional benchmark of $\geq 50\%$. As shown in Table 2, CLO2 (Modern Engineering Tools), CLO3 (Technical Reporting), and CLO4 (Teamwork) demonstrate high and stable performance. In contrast, CLO1 (Foundation Design) exhibits more pronounced variability.

Table 2. CLO Attainment Trends for Cohort from 2020 to 2023

CLO	2020	2021	2022	2023
CLO1	129	51	65	51
CLO2	140	141	89	98
CLO3	144	136	81	97
CLO4	144	141	89	97
Students/Cohort	144	141	89	97

CLO1 demonstrates robust attainment related to foundation design competency, reflecting students' ability to perform bearing capacity analysis, settlement evaluation, and design under complex soil conditions. Observed variations are attributed to cohort characteristics and assessment calibration rather than deficiencies in learning.

CLO2 shows consistently high attainment values, indicating effective integration of geotechnical software into teaching. The dedicated mini-project ensures students gain hands-on exposure to digital tools, reinforcing computational literacy essential for modern geotechnical practice.

CLO3 and CLO4 exhibit improving attainment in later cohorts, highlighting the positive impact of project-based learning, technical report writing, and peer evaluation. These outcomes demonstrate that Foundation Engineering can effectively cultivate professional skills beyond technical knowledge.

4.2 Normalised Attainment Index (NAI) and Threshold Benchmarking

To facilitate a fair comparison, the data was converted into a Normalised Attainment Index (NAI), where 1.0 represents the peak historical attainment. Across all four academic cohorts (2020–2023), all CLOs meet or exceed the $\geq 50\%$ attainment benchmark, with no sustained under-attainment observed.

- **Longitudinal Comparison:** Normalization mitigates scale bias caused by cohort size and varying assessment difficulties.
- **Threshold Achievement:** Figure 2 benchmarks these trends against the institutional threshold (NAI ≥ 0.50). Most cohorts maintain performance well above this baseline.
- **Design Complexity (CLO1):** Marginal under-attainment in CLO1 for specific cohorts (NAI of 0.40 in 2021 and 2023) reflects the higher cognitive demands and open-ended nature of foundation design rather than a deficiency in instruction.

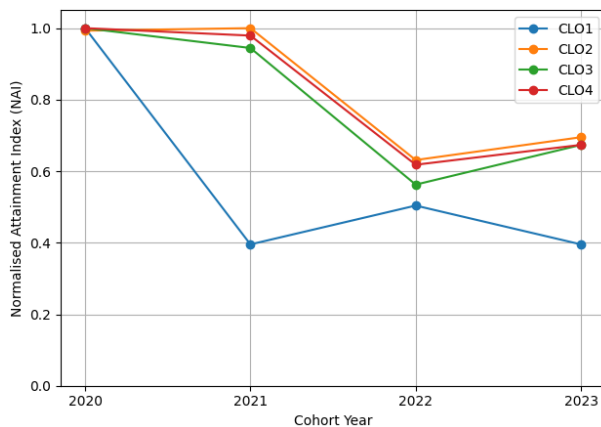


Figure 1. Normalised Course Learning Outcome (CLO) attainment trends for the Foundation Engineering course across four academic cohorts (2020–2023).

Note: Attainment values are normalised using the maximum observed attainment for each CLO to enable fair longitudinal comparison across cohorts.

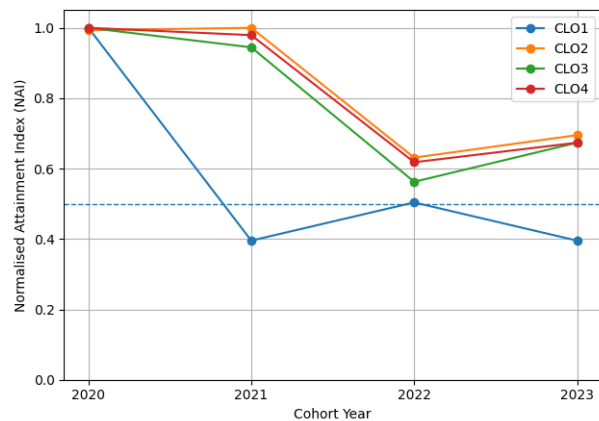


Figure 2. Benchmarking of normalised Course Learning Outcome (CLO) attainment against the institutional attainment threshold (NAI = 0.50).

Note: The dashed line represents the minimum acceptable attainment benchmark in accordance with Outcome-Based Education (OBE) practice.

Figure 1 presents normalised CLO attainment trends across cohorts, enabling fair longitudinal comparison by mitigating cohort size and assessment scale effects. Figure 2 benchmarks these trends against the institutional threshold (NAI = 0.50), confirming satisfactory achievement of intended learning outcomes. Marginal under-attainment in CLO1 for selected cohorts reflects the higher cognitive demand and open-ended nature of design assessments rather than instructional weakness.

4.3 Visual Heatmap Diagnostics

Visual analytics through heatmaps provide a rapid diagnostic tool for identifying performance patterns. Figure 3 presents a heatmap that provides an intuitive visual comparison of CLO attainment across cohorts. CLO2–CLO4 demonstrate consistently stronger attainment (lighter intensity), while CLO1 shows greater dispersion across cohorts, consistent with the higher cognitive and analytical demand of design-intensive assessments. The binary CLO attainment heatmap provides a rapid visual verification of outcome achievement across cohorts. All CLOs meet the institutional attainment benchmark (NAI ≥ 0.50) in most cohorts.

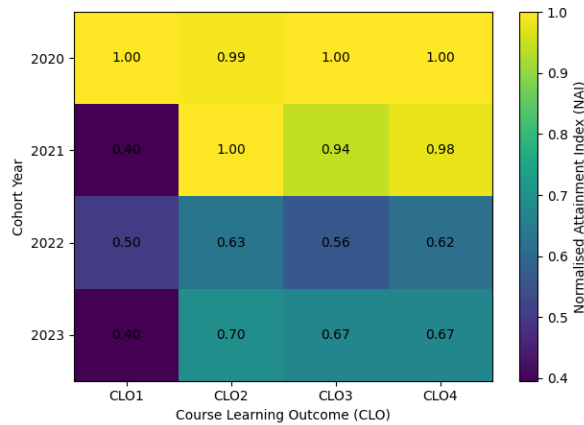


Figure 3. Heatmap of Normalised Course Learning Outcome (CLO) attainment trends for the Foundation Engineering course across four academic cohorts (2020–2023).

Note: Attainment is expressed as a Normalised Attainment Index (NAI) computed by dividing each CLO attainment value by its maximum observed value across cohorts. The institutional benchmark corresponds to $NAI \geq 0.50$ (i.e., $\geq 50\%$ attainment threshold) (Boddy, et. al., 2022).

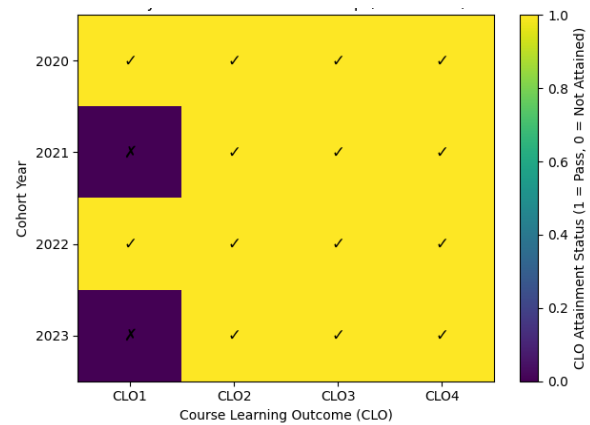


Figure 4. Binary heatmap of Course Learning Outcome (CLO) attainment for Foundation Engineering across four academic cohorts (2020–2023), based on a normalised attainment threshold of $NAI \geq 0.50$ (Boddy, et. al., 2022).

Note: A value of 1 (✓) indicates CLO attainment meeting or exceeding the institutional benchmark, while 0 (X) indicates attainment marginally below the benchmark.

Marginal under-attainment is observed only for CLO1 (foundation design) in selected cohorts, reflecting the inherently complex and open-ended nature of design-based assessments. Importantly, no CLO exhibits sustained under-attainment across consecutive cohorts, satisfying Outcome-Based Education and accreditation requirements.

This observation is consistent across the normalised trend analysis, threshold benchmarking, and heatmap diagnostics (Figures 1–4). Based on the binary CLO attainment analysis shown in Figure 4, targeted CQI actions were focused on CLO1 through enhanced design scaffolding and formative feedback, while maintaining existing strategies for CLO2–CLO4 due to consistent attainment.

4.4 Triangulation of Assessment and Learning Domains

The assessment mapping presented in Figure 5 and Figure 6 confirms that the course maintains "*constructive alignment*" by evaluating outcomes through appropriate modes:

- **Cognitive Emphasis:** CLO1 is primarily linked to the final examination, testing higher-order analytical skills
- **Psychomotor Application:** CLO2 is dominantly assessed through the software-based mini-project.
- **Affective/Professional Skills:** CLO3 and CLO4 are evaluated via performance-based tasks like technical reports and peer evaluations, ensuring professional competencies are not reduced to written tests.

This triangulation supports the robustness of the CLO evaluation and supports accreditation requirements for a holistic graduate profile.

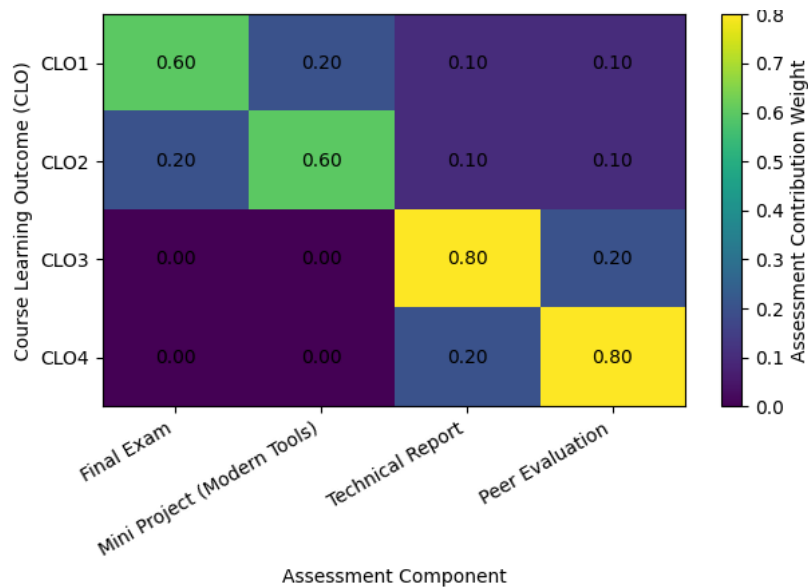


Figure 5. Heatmap illustrating the relative contribution of assessment components to Course Learning Outcome (CLO) attainment for the Foundation Engineering course.

Note: Values represent proportional contribution weights derived from assessment mapping. Higher intensity indicates stronger alignment between a CLO and a specific assessment component (Boddy, et. al., 2022).

Figure 5 demonstrates clear constructive alignment between Course Learning Outcomes and assessment components. CLO1 (foundation design) is primarily assessed through the final examination and design-oriented components, reflecting its strong analytical and cognitive emphasis. CLO2 (modern engineering tools) is dominantly evaluated through the software-based mini project, confirming intentional alignment with digital competency development. CLO3 (technical communication) and CLO4 (teamwork) are strongly supported by technical reporting and peer evaluation, respectively, ensuring that professional skills are assessed through authentic, performance-based tasks rather than written examinations.

The CLO × assessment mapping (Figure 5) confirms that each CLO is evaluated using assessment modes aligned with its learning domain. Design competency (CLO1) is emphasised through examinations and analytical tasks, while modern tool usage (CLO2) is assessed via project-based software application. Communication and teamwork outcomes (CLO3 and CLO4) are primarily evaluated through technical reporting and peer evaluation, supporting authentic professional skill development. This alignment explains the observed stability in CLO attainment and guides targeted CQI actions.

Figure 6 demonstrates a clear triangulation between Course Learning Outcomes, assessment components, and Bloom's learning domains. CLO1 (foundation design) is strongly aligned with cognitively demanding assessments through the final examination, reflecting higher-order analytical and evaluative skills. CLO2 (modern engineering tools) shows dominant alignment with psychomotor learning via the software-based mini project, confirming authentic assessment of computational competency. CLO3 (technical communication) and CLO4 (teamwork) are strongly aligned with affective and higher-order cognitive domains through technical reporting and peer evaluation, ensuring professional skills are evaluated using performance-based methods rather than written tests alone.

The triangulated mapping (Figure 6) confirms that learning domains are systematically distributed across assessment components, preventing over-reliance on cognitive testing while ensuring balanced development of psychomotor and affective competencies. This triangulation supports both CLO attainment robustness and accreditation requirements for holistic graduate attribute development.

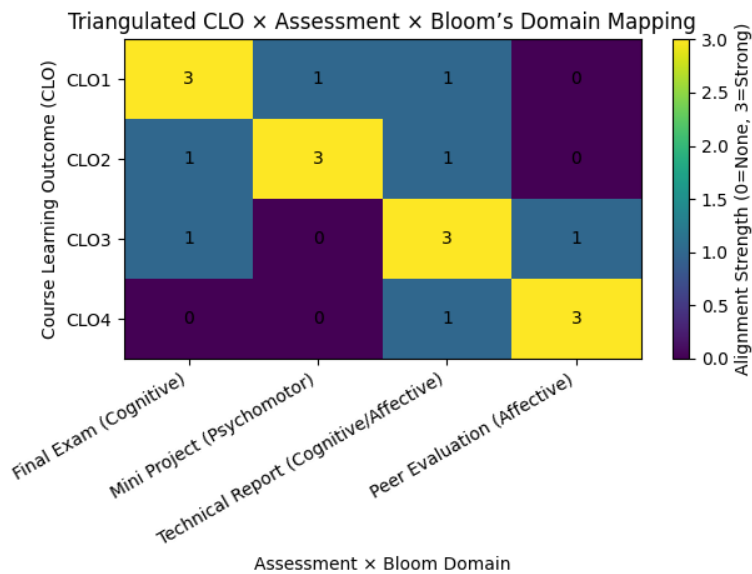


Figure 6. Triangulated mapping of Course Learning Outcomes (CLOs), assessment components, and dominant Bloom's learning domains for the Foundation Engineering course.

Note: Alignment strength is represented on a four-level scale (0 = none, 1 = low, 2 = moderate, 3 = strong), illustrating the intentional distribution of cognitive, psychomotor, and affective learning domains across assessment modes (Boddy,et. al., 2022).

5 Discussion

The longitudinal analysis confirms that an institutional threshold of $\geq 50\%$ (or $NAI \geq 0.50$) provides a defensible baseline for CLO attainment in design-intensive engineering courses. While CLO2, CLO3, and CLO4 demonstrate strong and stable performance, the dispersion observed in CLO1 (Foundation Design) warrants deeper pedagogical interpretation.

5.1 Pedagogical Implications and Variability Analysis

The observed variability in CLO1 (Foundation Design) attainment highlights its role as a threshold concept within the geotechnical curriculum. Unlike the procedural precision required for CLO2 (Modern Engineering Tools), which exhibited the lowest variability, foundation design requires a transition from rote calculation to engineering judgment. The dispersion in NAI scores for CLO1 suggests that students encounter 'troublesome knowledge' when navigating the inherent uncertainties of soil-structure interaction. *As students move from the Analyse to the Evaluate and Create levels of Bloom's Taxonomy*, as specified in the CLO1 action verbs, they must justify design decisions under complex ground conditions.

The marginal under-attainment observed in specific cohorts for CLO1 is not an indicator of instructional deficiency, but rather an affirmation of **assessment integrity**. It confirms that the alternative assessments, specifically the analytical design tasks are sufficiently rigorous to distinguish between superficial procedural knowledge and the deep, integrated understanding required for professional practice. To bridge this 'liminal space' in future iterations, the study proposes enhanced scaffolding specifically targeting the **'Recommendation'** and **'Justification'** criteria within the technical report rubrics, ensuring students can effectively synthesize empirical data into sound engineering decisions.

Several key pedagogical insights emerged:

- **Managing Cognitive Complexity:** The variability observed in CLO1 (Foundation Design) is a function of the open-ended and judgment-based nature of geotechnical problem-solving. This dispersion reflects learning complexity rather than instructional deficiency.

- **Effectiveness of Authentic Tools:** The consistent high attainment in CLO2 indicates that dedicated, software-based mini-projects effectively bridge the gap between theory and computational literacy.
- **Scaffolding Professional Skills:** The progressive improvement in CLO3 and CLO4 demonstrates that utilizing performance-based rubrics for technical reporting and peer evaluation allows students to self-regulate and refine their professional competencies over time.
- **Normalization as a Fairness Tool:** The application of the Normalised Attainment Index (NAI) ensures that longitudinal comparisons remain fair and are not penalized by cohort size or assessment rigor.

While this study provides robust longitudinal insights, it is limited to a single course context within a specific engineering discipline. Nevertheless, the proposed benchmarking framework and interpretive approach are transferable to other design-intensive engineering courses where learning complexity and professional judgment play a central role.

6 Conclusion

The Foundation Engineering course demonstrates sustained attainment of all learning outcomes above institutional benchmarks. The integration of statistical normalization and visual analytics strengthens the credibility of educational evaluation and supports the holistic development of future civil engineers. This framework demonstrates that engineering education can simultaneously deliver high-level technical excellence, digital competency, and professional skills, ensuring graduates are industry-ready and capable of navigating the uncertainties of modern geotechnical practice.

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