



Implementing a Modern Hybrid Geology Curriculum: A Case Study from a South African University

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Abstract. Contemporary geology education is increasingly required to advance adaptability, intellectual agility, and professional competence in response to 21st century societal and industry needs. Whilst quality assurance and accountability frameworks underscore employability, limited clarity remains regarding the alignment between university geology curricula and the evolving societal and industry demands. This study examined the implementation of a geology curriculum at a recently established university in the Northern Cape Province of South Africa using a hybrid learning model. The model incorporated conventional face to face interactive discussions with pre-recorded online learning materials leveraging smart technologies to support authentic, personalised learning. The implementation efficacy was evaluated through solicited comments from external examiners, peer reviews, institutional and industry experts, and by using students' performance and feedback. Students' learning was evaluated through moderated online and in person theoretical assessments, complemented by field and laboratory-based practicals, and ultimately looking at pass rates. In contrast, students' feedback was collected anonymously using a suggestion box and by following a standardised institutional questionnaire designed for quality promotion and assurance evaluation, administered at the end of 2025. Statistical triangulation across the diverse data sources show that the hybrid delivery model can enhance students' theoretical comprehension, practical competencies, preparedness for professional practice, and sustainable societal involvement. The study contributes empirical evidence from a resource constrained and under researched context, demonstrating how aligned hybrid curriculum design can strengthen teaching, learning, and assessment practices in geology education. These insights inform ongoing debates on curriculum innovation, quality assurance, and industry relevance in higher education.

25 1 Introduction

South African universities are subjects to transformation in response to abrupt advancing technological shift, intensifying demands for graduate employability, and heightened societal expectations regarding sustainability and social responsibility. These concerns have been further amplified in the post Covid19 context, where disruptions to conventional modes of teaching and learning exposed structural vulnerabilities while simultaneously gravitating pedagogical innovation (Bond et al., 2024; 30 Zawacki-Richter et al., 2019). Geology is closely aligned with resource extraction, environmental management, natural



resource sustainability, and regulatory governance. It relies heavily on experiential learning, field based and laboratory practicals (Henríquez, 2025). Integrative reasoning covers spatial and temporal scales. Within this context, geology education occupies a complex position between universities and the mineral industry. Consequently, the design and implementation of the geology curricula must articulate its integrity coherent to technological adoption, and evolving societal and industry expectations (Dolphin et al., 2019; Speir et al., 2022; Argylian et al., 2024).

Contemporary curriculum theories emphasise the alignment of learning outcomes, pedagogy, and assessment within comprehensible learning designs that support deep approaches and transferable learning (Prideaux, 2003; Boitshwarelo and Vemuri, 2017; Aadil and Mohammad, 2025). Constructivist and transformative learning theories provide a prevalent theoretical foundation for such alignment, highlighting active engagement, contextualised knowledge creation, and the development of reflective, self-directed students (Ramsden, 2003; Illeris, 2007; Pajares, 2008; Aadil and Mohammad, 2025). In geology, these theories are operationalised through fieldwork, laboratory activities, practical learning, and increasingly through digitally supported settings that enable visualisation, modelling, and data interpretation. In the context of South Africa and Africa at large, empirical studies consistently highlight misalignments between university geology curricula and the practical, analytical, and professional competencies required by the mineral extraction industry, particularly in cases characterised by accelerated technological transformation and constrained institutional resources (Dolphin et al., 2019; Speir et al., 2022). Geology graduates entering both public and private sector are frequently enrolled in structured development programmes to bridge the gap between university training and industry performance demands, which often extend beyond core geological competencies to include entrepreneurial capability, advanced computer literacy, project management, and emotional intelligence, among other skills.

The post Covid19 expansion of hybrid, digital, and AI supported teaching has intensified debates concerning the pedagogical legitimacy, equity implications, and epistemic consequences of digital transformation in geology training (Selwyn, 2019; Williamson and Eynon, 2020). While virtual field experiences, learning management systems, and AI enabled feedback tools proven to enhance accessibility, flexibility, and students' engagement, concerns persist regarding their capacity to replicate the tacit and contextual dimensions of geological fieldwork (Dabbagh et al., 2019; Zhao et al., 2020; Ruberto et al., 2023). These controversies are particularly salient in newly established universities and in the Global South, where infrastructure limitations, staffing constraints, and students' under-preparedness determine both the strengths and limitations of curriculum innovation.

Drawing on Prideaux's (2003), this study examines the initial enactment of an undergraduate geology curriculum at a recently established South African university. Grounded in contemporary curriculum theories and informed by post Covid19 pedagogical dialogues, the study elucidates how hybrid teaching models, active learning strategies, and emerging smart technologies can be interwoven with field and laboratory practicals to support students' learning, professional readiness, and societal relevance. By critically reflecting on empirical evidence from curriculum mapping, assessment outcomes, peer



reviews, and students' feedback, the study contributes to current scholarly discussions on curriculum alignment, digital pedagogy, and quality assurance in geology education, while offering contextually grounded insights for universities navigating similar structural and epistemic challenges (Prideaux, 2003; Aadil and Mohammad, 2025).

2 Literature review

The study critically reviews previously published literature relevant to undergraduate geology curriculum implementation, with particular attention to post Covid19 transformations in higher education. The review synthesises foundational curriculum theories, pedagogical models in undergraduate geology education, and academic impacts of hybrid learning, digital technologies, and industry alignment. Furthermore, the study interrogates current discussions, contradictions, and gaps in the literature, establishing the conceptual and empirical foundations that inform the present study. It considers theories specific to geology curriculum, subsequently looking at emerging post pandemic trends directing teaching, learning, and assessment methods.

2.1 Theoretical foundations of curriculum implementation

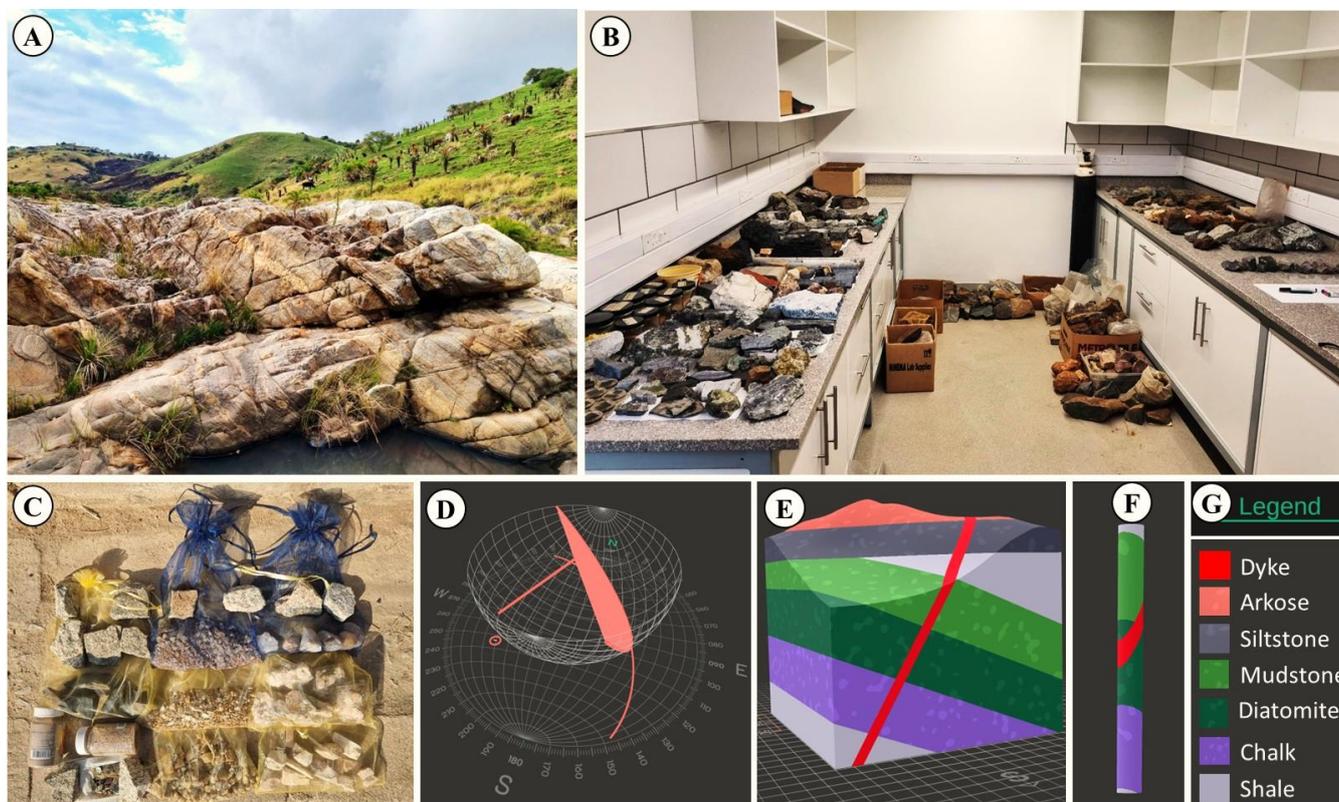
Geology curriculum at universities has long been conceptualised as more than a static syllabus, encompassing the objectives, practices, experiences, and outcomes of learning (Prideaux, 2003; Rogers et al., 2022). In general, early curriculum models were predominantly discipline based, emphasising content transmission and mastery of canonical knowledge (Toohey, 1999; Bakky, 2020). While such approaches remain influential in scientifically grounded disciplines such as geology, they have been increasingly critiqued for insufficiently addressing students' diversity, employability, and societal relevance.

Contemporary geology curriculum theory is centered around constructive alignment, whereby teaching activities, assessment strategies, and learning outcomes are coherently aligned to promote deep critical deduction (Prideaux, 2003; Biggs, 2003, 2014; Jaiswal, 2019). This perspective places curriculum as an intertwined system rather than a collection of discrete components. Boitshwarelo and Vemuri (2017) extend this view through learning design frameworks that emphasise strategic alignment between curriculum goals and pedagogical enactment, highlighting the role of explicit design decisions in moulding students' learning experiences.

Transformative curriculum theory has been considered to further expand the scope of geology curriculum design by emphasising the development of graduates as critical, reflective, and socially responsible professional geologists (Barnett and Coate, 2006; Nixon, 2008; Collen, 2016). From this perspective, geology curriculum must engage not only with geological knowledge but also with questions of identity, ethics, and purpose. In applied geology, transformative approaches are particularly relevant given the geology's interconnectedness with environmental sustainability, resource governance, and societal necessities.

2.2 Learning theories informing geology education

A constructivist learning theory provides the pedagogical foundations upon which geology curriculum design decisions are enacted. This theory views knowledge as actively created through experience and interaction, and has been adopted for geology education (Ramsden, 2003; Illeris, 2009; Satish, 2024). The constructivism underpins inquiry learning, fieldwork, and laboratory activities, where students interpret complex, often ambiguous data rather than reproduce fixed solutions (Fig. 1b).



100 **Figure 1: (a) Field mapping of tilted geological strata. (b) Laboratory display of rock and mineral specimens. (c) Rock and mineral samples used in laboratory practicals for identification and description. (d) Stereonet projection of bedding planes measured at the outcrop shown in (a). (e) Three-dimensional visualisation model developed using the Visible Geology application, generated in accordance with instructional design principles to support higher order learning. (f) Illustration of drill core derived from the 3D block model generated in Visible Geology. (g) Lithological legend.**

A competing theory is the experiential learning theory which further reinforces the centrality of fieldwork and hands on practice in geology training (Fig. 1a; Fig. 1e). Kolb's experiential learning cycle (King, 2012; Henríquez, 2025), although not geology specific, has been frequently invoked to justify the integration of observations, reflections, conceptualisations, and experimentation in field-based curricula. Empirical studies consistently demonstrate that field experiences enhance conceptual understanding, spatial reasoning, and professional identity formation among geoscience students (Dolphin et al., 2019). Alternatively, transformative learning theory complements constructivist and experiential theories and emphasizes critical



110 reflection and perspective transformation (Barnett and Coate, 2006; Satish, 2024). In geology training, transformative learning is increasingly associated with sustainability education, ethical reasoning, and the interrogation of extractive practices, aligning geology learning with broader societal and environmental imperatives (UNESCO, 2021).

2.3 Curriculum alignment and industry relevance in geology

115 A persistent enquiry in the literature is the perceived misalignment between university geology curricula and industry expectations. Studies across different national contexts report that graduates often lack sufficient practical skills, applied problem solving abilities, and familiarity with industry standard technologies (Bentley and Watts, 2017; AGI, 2018). This gap has prompted calls for closer collaboration between universities, private industries, and professional bodies in curriculum design and review.

120 Professional accreditation frameworks and qualification standards such as those provided by South African qualification authority (SAQA), national qualification framework (NQF), and council on high education (CHE), play a key role in curriculum alignment. While such frameworks ensure consistency, credibility, and portability of qualifications, scholars caution that over reliance on prescriptive standards may constrain curricular innovation and contextual responsiveness (CHE, 2007; O’Riordan, 2018; NQF, 2020). Therefore, balanced approaches that treat regulatory frameworks as guiding mechanisms rather than exhaustive templates are necessary.

125 2.4 Digital transformation and hybrid learning

The Covid19 pandemic acted as a catalyst for widespread adoption of digital and hybrid teaching models, fundamentally reforming higher education practices (Zawacki-Richter et al., 2019; Bond et al., 2024). In geology education, this shift has intensified experimentation with virtual field experiences (VFEs), learning management systems, and online assessment tools (Zhao et al., 2020). Empirical studies suggest that well designed hybrid models can enhance flexibility, accessibility, and students’ engagement, particularly for students with geographical, financial, or physical constraints (Dolphin et al., 2019; Ruberto et al., 2023). However, the literature (e.g., Speir et al., 2022), also highlights significant pedagogical constrains. Critics argue that digital substitution risks diluting the embodied and contextual dimensions of geological learning, particularly when virtual tools merely replicate conventional fieldwork without deeper pedagogical redesign (Zhao et al., 2020). Consequently, recent scholarships emphasise the significance of pedagogically derived, rather than technologically driven, integration of digital tools.

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2.4.1 Artificial intelligence in geology education

Artificial intelligence (AI) represents a growing frontier in universities, with increasing interest in its applications for personalised learning, assessment, and feedback (Luckin et al., 2016; Zawacki-Richter et al., 2019). Despite this growth, research on AI in geology remains limited. Existing studies largely focus on generic Science, Technology, Engineering, and



140 Mathematics (STEM) contexts, leaving questions about how AI intersects with geology’s distinctive epistemic practices, such as spatial visualisation, interpretive uncertainty, and field-based training (Bandi R., 2024).

According to previously published literature (e.g., Selwyn, 2019; Williamson and Eynon, 2020) there exist both opportunities and risks associated with AI adoption (Fig. 2). Admittedly, AI enabled tools can support adaptive learning, offer immediate feedback, and simplify complex data visualisation, all of which are highly relevant to geological education. Conversely, data
145 privacy, algorithmic bias, over reliance on AI, and equity of access remain skewed. These challenges underscore the need for empirically grounded, ethically informed frameworks to guide AI integration in geology curricula.

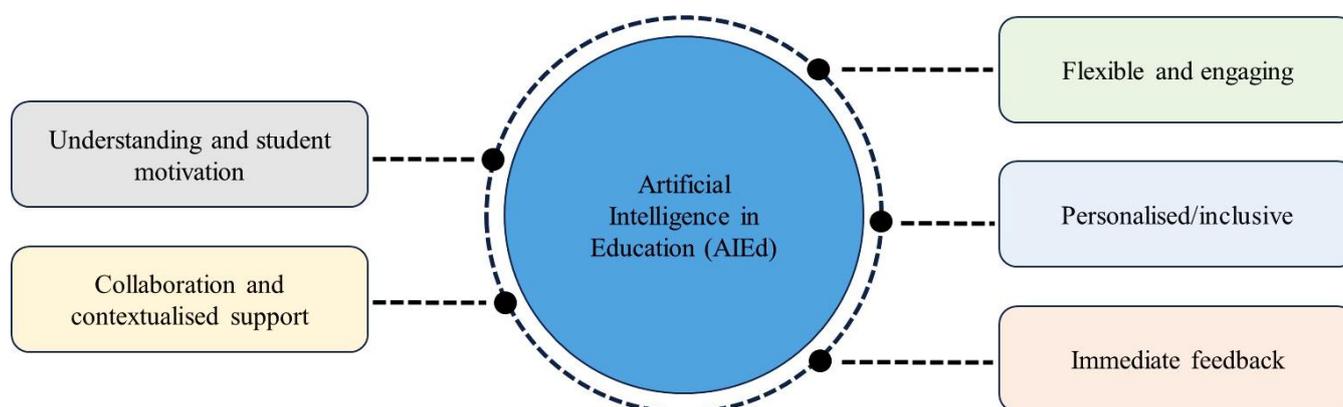


Figure 2: Mind map of positive impact of artificial intelligence on students’ critical thinking and creativity (Klutka et al., 2018; Holmes et al., 2019; Hutson et al., 2022; Bond et al., 2024).
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2.5 Assessment practices in geology education

Assessment is widely recognised as a central driver of students’ learning behaviour (Ramsden, 2003). In geology, effective assessment must capture both conceptual understanding and practical competence. These are often achieved through multimodal approaches that combine written examinations, field reports, laboratory practicals, and oral presentations (Fig. 3).
155 Bloom’s revised taxonomy (Anderson and Krathwohl, 2001; Lam and Ng, 2026) was consulted to structure progression from lower order knowledge recall to higher order analysis, synthesis, and evaluation. Post Covid19 literature highlights increased reliance on digital and formative assessment strategies, including online quizzes, automated feedback, and peer assessment (Holmes et al., 2019). While the aforementioned approaches offer efficiency and scalability, scholars caution that they must be carefully aligned with learning outcomes to avoid superficial learning and not to compromise academic integrity (Rogers et al., 2022).
160 Figure 3 illustrates a five-step thought process integrated into assessments to address challenges of intricate geological concepts.

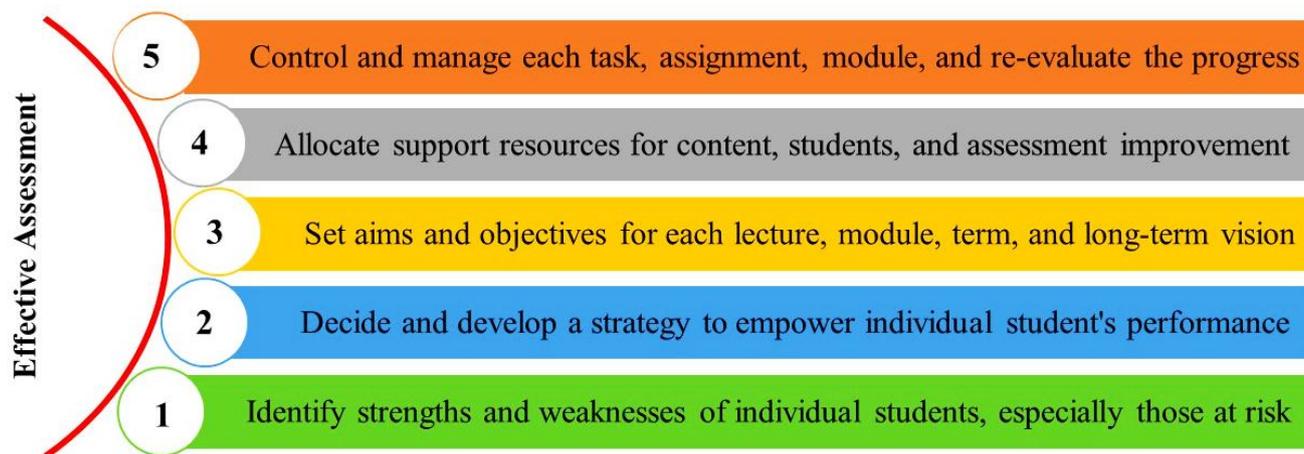


Fig. 3: **Thought process for effective assessment.**

165 2.6 Identified gaps in the literature

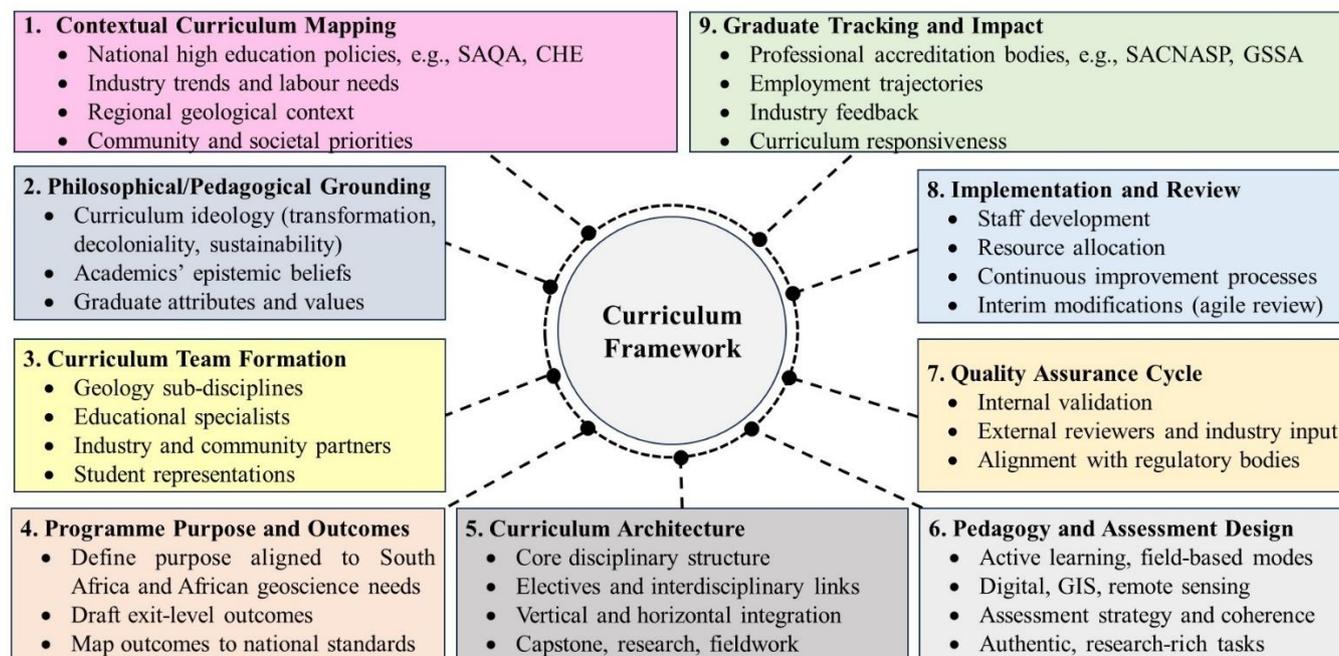
Despite extensive research, several gaps persist. Firstly, there is limited empirical research on geology curriculum implementation in newly established universities, particularly in the Global South. Secondly, longitudinal studies examining the sustained impact of hybrid and AI supported curricula on graduate outcomes remain limited. Lastly, there is insufficient integration of curriculum theories, disciplinary epistemology, and institutional context within a single analytical framework.

170 3. Research methodology

The research design, methodological approach, and analytical procedures adopted in this study were selected to align with the study's aim of examining the implementation of an undergraduate geology curriculum within a post Covid19 higher education context. Given the exploratory and context specific nature of curriculum research, a qualitative dominant approach was adopted, supported by descriptive quantitative data where appropriate. The study incorporates details of the research paradigm, study context, data sources, data collection procedures, analytical methods, and measures carried out to ensure trustworthiness and ethical integrity, in accordance with accepted standards in educational research (Spiller, 2012).

180 3.1 Research paradigm and design

The study fits within an interpretivist research paradigm, which assumes that educational phenomena are socially constructed and best understood through the meanings ascribed by participating private industries, society, and the university concerned (Cohen et al., 2007; Pervin and Mokhtar, 2022). This paradigm was considered appropriate and adopted for this geology curriculum study, where policy, pedagogy, and practice are intertwined in complex and context dependent ways (Fig. 4). A qualitative case study design was therefore created to enable in depth examination of curriculum processes within a bounded institutional setting.



185 **Figure 4: Modern Curriculum Framework (Boitshwarelo and Vemuri, 2017).**

The study approach integrated multiple data sources, e.g., curriculum documents, assessment records, peer review reports, and students' feedback, facilitating a holistic understanding of curriculum alignment, pedagogical goals, and implementation deliverables (Yin, 2018; Aadil and Mohammad, 2025). While the findings are not intended to be statistically generalisable, they offer analytical generalisability by contributing theoretically and empirically derived insights to the broader literature on geology education and curriculum reform.

3.2 Study context

The study was carried out at a newly established public university in South Africa offering an undergraduate Bachelor of Science programme with a major in geology for the first time in 2025. The institution's operations are governed by the CHE, SAQA, and NQF. These national regulatory frameworks prescribe minimum standards for programme accreditation, learning outcomes, and assessment practices. The geology curriculum in this study was formulated during a period of institutional expansion and post Covid19 recovery. It is characterised by infrastructural constraints, evolving staffing profiles, and a students' cohort with diverse academic backgrounds, limited prior exposure to geology, and limited access to digital devices.

3.3 Data sources

200 Multiple data sources were consulted to support triangulation and enhance the credibility of the findings. These include: (i) Consultation with curriculum and policy documents providing module outlines, programme specifications, curriculum road



maps, and assessment strategies. Institutional teaching and learning policies were analysed to decipher alignment between learning outcomes, content, pedagogy, and assessment. (ii) Reviewing aggregated students' performance data, incorporating pass rates and assessment results, to identify patterns in learning progression and areas of curriculum strength or challenge. 205 (iii) Analysis of qualitative and quantitative students' feedback of teaching and learning to capture students' perceptions of curriculum coherence, teaching theories, and assessment procedures. (iv) Examination of internal and external peer review reports, moderation feedback, and quality assurance comments and recommendations to assess curriculum compliance, academic standards, and professional relevance. (v) Informal consultations with disciplinary colleagues and curriculum specialists to inform iterative curriculum refinement and contextual interpretation of findings.

210 3.4 Data collection

Data collection occurred over a series of academic sessions to capture early implementation phase of the curriculum. Documentary data were systematically collected from institutional repositories and programme records prior to the commencement of the semester. Students' feedback data were solicited halfway through the semester by asking students to send **anonymous comments** to a suggestion box. Further students' data collection was performed using standardised 215 institutional module and lecturer evaluation questionnaire instruments, e.g., quality promotion and assurance (QPA) administered at the end of the year 2025 (Fig. 6). Following the conclusion of academic assessment cycles, students' performance data were collated from departmental records and presented in an anonymised form prior to analysis (Table 2). **No direct** collection of identifiable personal information from students or staff (Fig. 7).

3.5 Data analysis

220 Qualitative data were processed using thematic analysis approach, following the procedures outlined by Braun and Clarke (2006). **Initial criteria** focused on curriculum alignment, pedagogical approaches, assessment practices, and implementation challenges. The criteria were subsequently grouped into broader themes (Fig. 5) reflecting theoretical constructs from curriculum and learning theories, such as **constructive alignment**, active learning, and **transformative engagement**. Document analysis involved systematic comparison of stated learning outcomes, teaching activities, and assessment tasks to identify 225 coherence and gaps within and across themes and modules. Quantitative data, including pass rates (Table 2) and assessment scores (Table 3), were analysed descriptively to support qualitative interpretations and to identify trends over time. The **integration of qualitative and quantitative findings** enabled a nuanced interpretation of curriculum effectiveness and implementation dynamics.

3.6 Trustworthiness and rigour

230 To ensure trustworthiness, the study adopted established qualitative research criteria of **credibility, dependability, confirmability, and transferability** (Lincoln and Guba, 1985; Sirwan, 2024). Credibility was enhanced through data triangulation across multiple sources and iterative peer consultation (Fig. 5). Dependability was supported by maintaining a



235 clear audit trail of data sources, analytical decisions, and curriculum revisions. Confirmability was addressed through reflexive
engagement with the data and alignment of interpretations with documented evidence. While transferability is limited by the
study design, detailed contextual description enables readers to assess the relevance of findings to comparable institutional
settings.

3.7 Ethical considerations

240 The research utilised secondary institutional data and anonymised students' feedback, ensuring confidentiality and compliance
with data protection requirements. The study adhered to principles of academic integrity, transparency, and respect for
participants, with findings reported in aggregate form to avoid individual identification.

4 Results and description

245 This study presents the empirical findings from the initial implementation and evaluation of a hybrid, technology enabled
geology curriculum at a newly established university in the Northern Cape Province of South Africa. The results are derived
from external examiner evaluations, peer reviews, students' performance data, and students' feedback questionnaires collected
during the 2025 academic year.

4.1 External and internal validation

250 The legitimacy and quality of the geology curriculum at the study university were validated through moderation by internal
and external examiners. As summarised in Table 1, two external examiners from two separate South African universities
consistently affirmed the fairness and adequacy of the examinations as assessments of the module and course outcomes. They
also confirmed that the structure of the examination questions was a fair reflection of the module content. While most questions
were deemed fair and unambiguous, some were noted for improvement. The marking rubrics were considered accurate and
adequate, and the mark allocation appropriate. Adequate time was allowed for answering the questions.

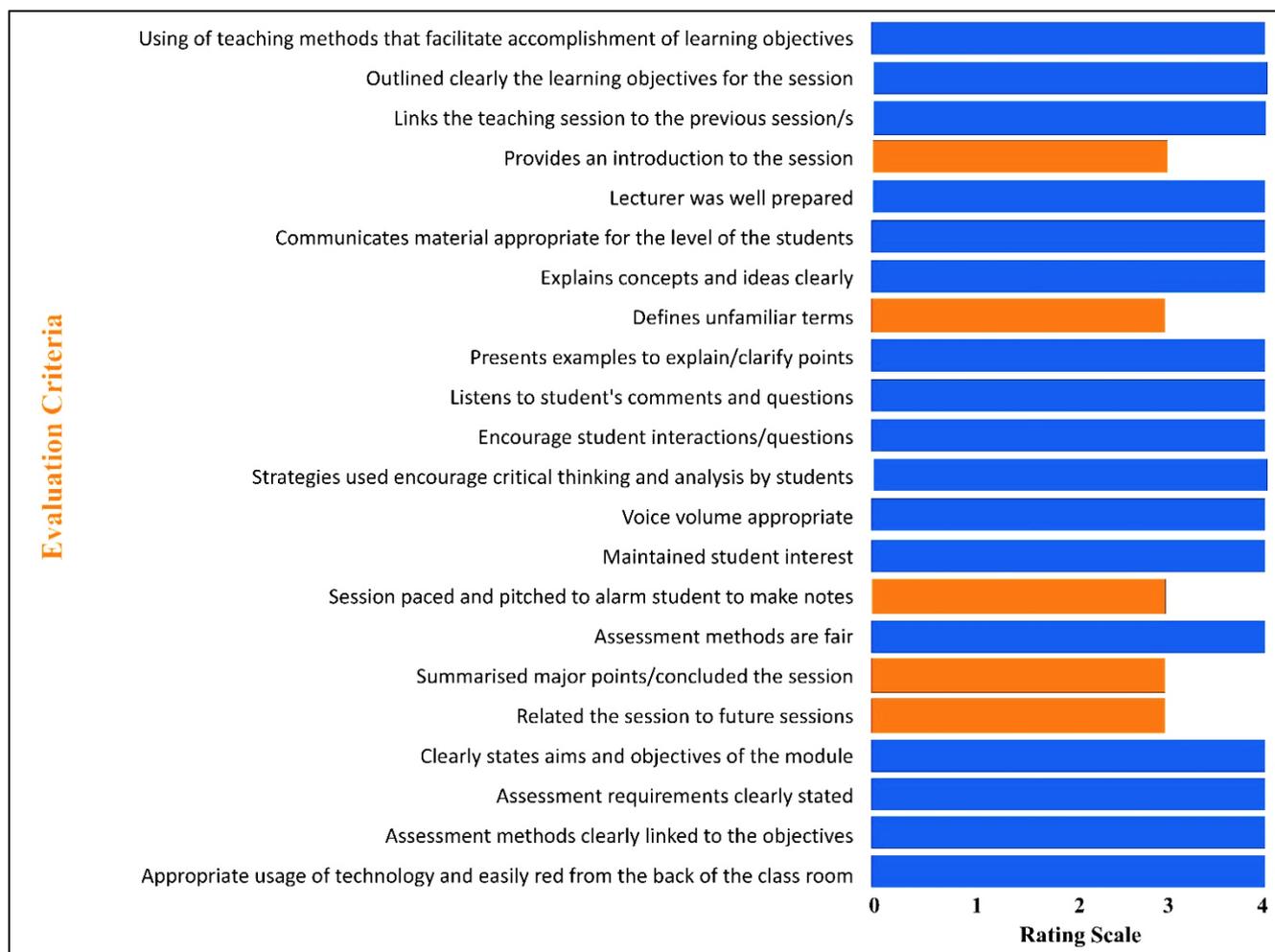
255 **Table 1: External evaluation of draft examination question paper by two external examiners from two separate South African
universities.**

Questions	Comments
Do you consider the examination fair and adequate assessment of the module outcomes?	Yes
Was the examination question paper structure a fair reflection of the module content?	Yes
Were the questions fair and unambiguous, if no, please elaborate?	need ratification
Was the information on the marking scheme or memorandum accurate and adequate?	Yes
Was the mark allocation to each of the questions appropriate?	Yes



Was adequate time allowed for the answering of the examination questions?	Yes
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Further internal validation through peer review rated the first-year geology module as excellent. Figure 5 details the peer evaluation outcomes by one internal member of academic staff, showing most items with a score of four, which implies that the goals were accomplished very well. Items that are clustered at four show consistently strong performance across preparation, clarity, engagement, assessment, and organisation. Key strengths highlighted encompass meticulous lecturer preparation, clear articulation of learning objectives, effective correlation between sessions, strong subject mastery, and clear explanation of concepts with annotated illustrations inclusive of local examples. Teaching methods were consistently found appropriate for achieving learning outcomes and students' academic levels. Minor areas identified as satisfactory with a score of three include the introduction of sessions, definition of unfamiliar terms, session pacing, and ability to allow students to make notes, highlighting relative (but still positive) areas for refinement.





270 **Figure 5: Teaching evaluation outcomes across instructional, engagement, and assessment criteria (Bloxham et al., 2011). Note! Ratings are based on a four-point Likert type scale, 1 = poor and 4 = accomplished very well. Higher scores indicate stronger perceived performance for each evaluation criterion.**

Further quoted peer review comments:

275 “The delivery of the lecture was not adversely affected by logistical factors, as the venue was sufficiently spacious to accommodate all students comfortably, with adequate lighting and a well-functioning projector. The lecturer’s major strengths included a high level of confidence, thorough preparation, strong organisation, and deep subject knowledge. Concepts were explained clearly, with care taken to ensure that students understood the material before progressing to a different topic. While the lecture covered many topics in a single session, which could potentially be divided into two periods for improved pacing, the lecturer effectively maintained students’ focus and engagement throughout. Overall, the lecturer demonstrated patience and clarity, repeatedly explaining challenging concepts when necessary and actively encouraging students’ participation, 280 particularly among those initially hesitant to ask **questions.**”

4.2 Students’ performance

Students’ performance data gathered from 13 participants of Year Level 1 Introduction to Geology module, in 2025 indicate a high level of success. As shown in Figure 6a, the final module mark for a class size of 13 students had an average of **66%** and a **pass rate of 99%**. This positive outcome is attributed to the efficacy of aligning learning outcomes with assessment methods, 285 the dedication of academic staff, and the implementation of a **hybrid teaching model** (Fig. 6b).

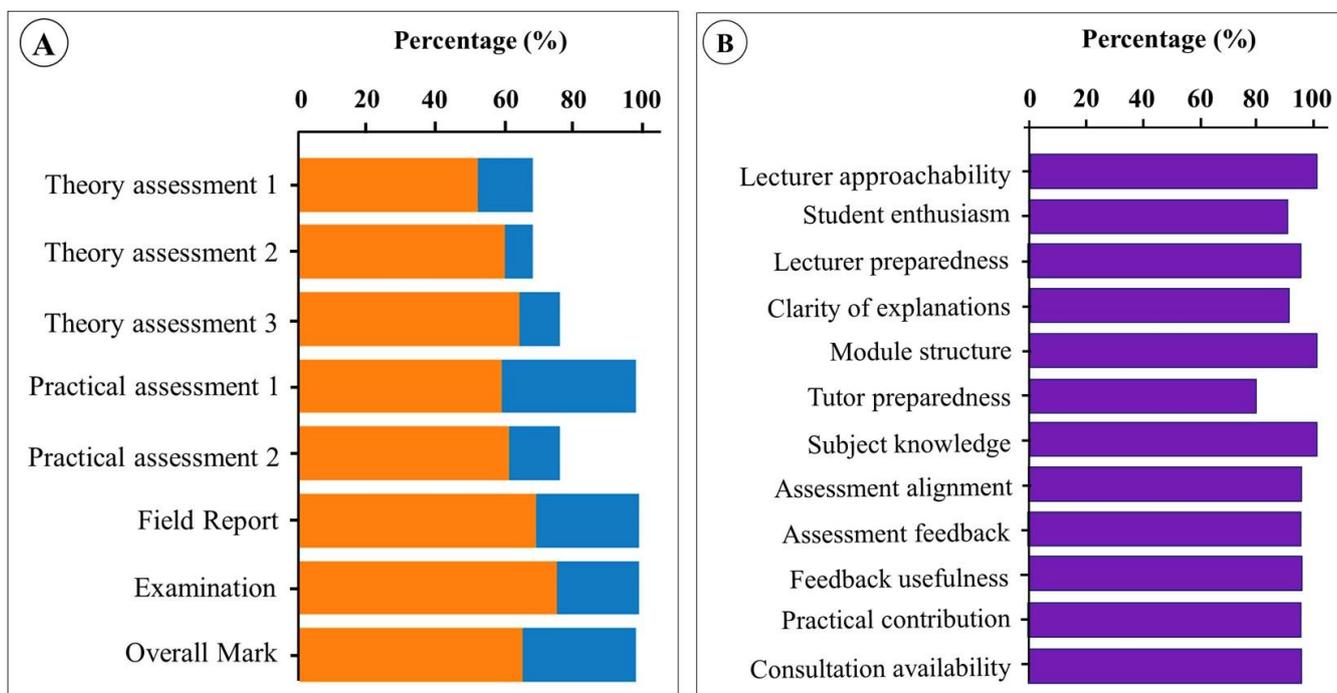


Figure 6: (a) – module performance summary showing assessment components on the x-axis and percentage (%) on the y-axis. Bars represent pass rates and class averages of 13 participating students, enabling comparison between overall success and mean performance. Strongest outcomes are observed in the field report, examination, and final module mark, whereas earlier theory assessments exhibit comparatively lower class averages despite satisfactory pass rates. (b) – summary of students’ feedback results.

4.3 Students’ evaluation

Students’ feedback collected from 13 participants by using QPA questionnaires consistently depict high satisfaction across various categories. The module quality, encompassing structure, coherence, and intellectual engagement, received an overall mean score of 95%. Lecturer performance was the highest rated category at 96%, indicating excellent preparedness, subject knowledge, and approachability. Assessment strategies, including content alignment, feedback provision, and usefulness, scored 95%. Practicals contribution to understanding scored 88%, with tutor preparedness being an area for potential improvement. Overall, the module exceeded expectations with a QPA rating of 95% (Fig. 7).

Students’ evaluation data reveal mostly positive perceptions of curriculum coherence and teaching effectiveness. High levels of agreement are reported in relation to the organisation of modules, alignment between teaching activities and the perceived relevance of module content to the field of geological. Lower but still favourable ratings are evident for workload manageability, particularly for exhaustive practical activities. Open ended response summaries, where included in the tables, highlight recurring themes related to the value of practical work, field experiences, and applied exercises to solve problems.



Concerns noted in the table are primarily logistical, including time constraints and access to resources, rather than pedagogical design issues.

A spider graph (Fig. 7a) illustrates the mean scores for the module, lecturer, assessment, practicals, and tutorial categories, confirming high scores across all aspects, particularly with high strength in theoretical delivery. Figure 7b provides a detailed visual representation of 13 students' responses across individual questions using a five-point Likert scale, where higher markers are clustered nearer to five and indicate more positive perceptions.

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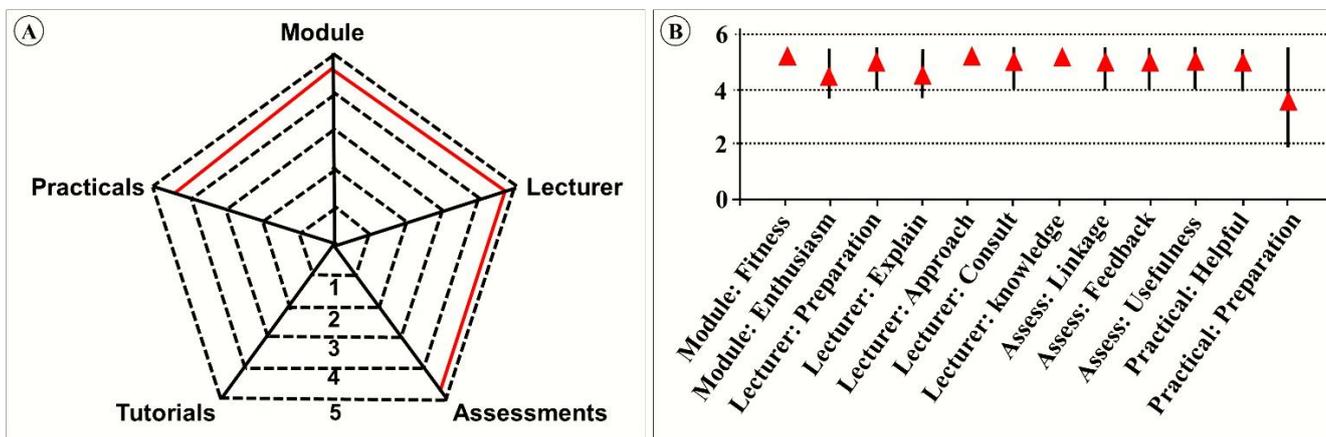


Figure 7: Students' evaluation of the programme and teaching and learning strategies using (a) – spider graph and (b) – five-point Likert scale.

Beyond the aggregated responses from all the 13 students (Figs. 6 and 7), Figure 8 presents additional example of qualitative feedback extracted from a follow-up email by one of the 13 participants who apparently had not been able to complete the online student evaluation survey. The student indicated that the semester was both intellectually enriching and enjoyable, expressing strong confidence in the standard of instruction, particularly with respect to the mineral microscopy component of the course. The feedback emphasised the lecturer's engaging teaching style, motivational guidance, and commitment to students' success, including additional support sessions. The student also noted the positive impact of structured time-management expectations and regular encouragement. A suggestion was made to incorporate mock tests and structured test reviews to further enhance assessment preparation.



Greetings Dr Tibane. I hope this finds you well.

I wanted to fill in the evaluation questionnaire but it said that I have already filled it in, so I thought I should send an email instead.

It has been an exciting semester, being taught by you has not only been educative but fun as well. I am sincerely grateful to have been taught by you. I've learned so much in such little time. I am very confident in saying that if we were to compete with other universities on the mineral microscopy course, we would definitely be in the first position. This speaks volumes about what a great teacher you are. Your teaching style has helped me and many other students in our class understand different topics easily, even the ones that seem scary and hard at first.

You taught us time management (something that I have been struggling with but getting better at over time) by saying that if we are seven minutes early then we are on time, but if we are on time then we are late. Your willingness to help, even if it meant coming in on weekends, just so we get extra classes that will help us pass. We are highly grateful. My favorite part about going to your classes is how you always give us a pep talk before, during, or after the class. Your words give me hope, hope that I can also achieve what you have achieved. They give me wisdom and a new perspective on how to view the world and everything in it. You are not only a lecturer but a father figure to all of us, and that makes you stand out from other lecturers, with that said, happy fathers Day in advance.

In terms of things that you can improve on, maybe, if possible, you can make mock tests so to prepare students for the test. You should have test reviews and go through a question that most students had difficulties with. However, I am extremely happy with how you teach.

Thank you so much for your dedication and keep up the good work.
Yours Sincerely,

325 **Figure 8: Unedited student's email to lecturer.**

Students were also asked to evaluate feedback from their human lecturer versus AI feedback. A majority of eight out of 13 students preferred human lecturer feedback and in person contact sessions. Contact with the lecturer enriched the dialogue and improved communication skills, verbally and digitally. An example of student email feedback (Fig. 8) further underscored the appreciation for effective teaching despite constraints. Conversely, five out of 13 students found AI generated feedback more
330 readable and detailed, aligning with findings from other studies (Escalante et al., 2023).

4.4 Challenges and limitations

Despite the positive outcomes, the study identified several challenges during curriculum implementation. Such challenges included resource constraints, particularly the absence of dedicated laboratory facilities and non-existent sample collections
335 which posed the initial difficulties. Fieldwork faced logistical challenges related to safety, transport, and equipment which led to delays and subsequent cancellations. Staffing was a significant limitation, with only one geologist appointed on a short-term fixed contract initially responsible for geology programme. Students' readiness varied widely, ranging across backgrounds in Mathematics, Biochemistry, Physics, and Chemistry, with many students having little or no previous exposure to geology.



340 Language and literacy barriers also impacted comprehension of technical vocabulary. Content overload was observed due to ambitious content coverage and students carrying multiple modules.

These challenges required additional foundational support, and several initiatives were implemented to help mitigate the identified limitations. Figure 1b–c illustrates donated geological teaching samples, which significantly enhanced practical instruction. The involvement of industry experts from a nearby operational mine, helped by providing scientific talks and training, and contributed to capacity building and curriculum quality.

345 **5 Discussion**

5.1 Programme Moderation

350 /The academic quality of the geology curriculum was strengthened through systematic moderation processes by two internal academic staff members and two external academics from two distinct South African universities. These processes affirmed the fairness, clarity, and adequacy of assessments as valid for the module and programme outcomes. The moderations confirmed the alignment between question structure and taught content. Such validation is imperative within a geology curriculum because assessment strategies must accurately judge higher-order competencies including analytical reasoning, applied problem-solving, and geological data interpretation rather than recalling (Barnett and Coate, 2006; Dolphin et al., 2019). The positive evaluation of marking rubrics, mark allocation, and time provision indicates that assessment practices were transparent, criterion-referenced, and pedagogically sound. From a constructive alignment perspective, as articulated by (e.g., 355 Biggs, 2003, 2014; Jaiswal, 2019), the moderations suggest coherence between intended learning outcomes, teaching and assessment activities. The identification of minor areas for refinement further reflects a quality enhancement ethos rather than systemic weakness. For the geology programme, such moderations not only uphold academic standards but also reinforces institutional credibility and comparability with broader disciplinary benchmarks, thus, ensuring that graduates' demonstrated competencies meet both academic and professional expectations.

360 **5.2 Students' performance**

Students' performance data for Year Level 1 in the 2025 Introduction to Geology module illustrate a high level of academic success, with a class mean of 66% and a pass rate of 99% (Fig. 6a). These findings signify that the current curriculum design is efficiently supporting foundational learning in geology, especially in developing concepts such as deep time to recognise principles such as the plate tectonics, orogeny, basin development, life evolution, mass extinctions, and climate change. The 365 strong performance is pedagogically significant in light of the principles of constructive alignment which argues that optimal learning occurs when intended learning outcomes, teaching and learning activities, and assessment approaches are coherently aligned (e.g., Biggs, 2003, 2014; Jaiswal, 2019; Hristov et al 2023). In geology, cognitive demands encompass spatial reasoning, critical thinking, and the interpretation of field and laboratory data, misalignment often leads to superficial learning



and fragmented conceptual comprehension. The present results therefore imply that alignment between clearly articulated
370 geological competencies and assessment practices promote deeper engagement and meaningful learning. Moreover, the hybrid
teaching model has reinforced this alignment by incorporating multimodal instruction with assessment methods that directly
measure geological skills. For the broader geology curriculum, these findings underscore the significance of outcome-driven
assessments implementation to enhance students' performance, retention, and progression within the geosciences.

5.3 Students' evaluation

375 Notably, Students' evaluation data reflect strong perceptions of curriculum coherence, constructive alignment, and teaching
effectiveness within the geology programme. A strong agreement regarding module organisation, alignment between teaching
and assessment, and disciplinary relevance, suggest that the curriculum operates as an integrated framework rather than a set
of discrete components. Although workload manageability received slightly lower, yet still positive ratings, particularly for
intensive practical activities, qualitative responses consistently emphasised the value of laboratory practices, field excursions,
380 and applied problem-solving exercises (Hristov et al., 2023). These study findings reaffirm experiential learning as central to
geology education. As an empirical and spatial science, geology requires the development of competencies such as geological
mapping, structural measurement, lithological logging, mineral identification, and geochemical interpretation skills that cannot
be created through didactic instruction alone. Authentic field experiences promote conceptual integration and facilitate transfer
of theory to complex real-world contexts (Barnett and Coate, 2006; Dolphin et al., 2019). Practical training also aligns with
385 competency expectations articulated by the GSSA and SACNASP, which emphasise the necessity of applied skills and
analytical problem-solving. Notably, students' concerns centred on logistical issues, time and resource access rather than
pedagogical implementation. This suggests that curriculum refinement should prioritise operational optimisation while
preserving the intensity of practice-based learning essential for producing work-ready geology graduates.

Students' evaluations of feedback modalities present significant implications for curriculum implementation in geology,
390 particularly in relation to dialogical pedagogy and formative assessment techniques. The majority preference (8/13) for human
lecturer feedback and in-person contact sessions reflect that relational and geology-embedded feedback remains pedagogically
significant. Geology is interpretive and inferential in nature requiring students to justify their approach to solving real-world
challenges, and such reasoning is often refined through iterative dialogue and practice. The preference for lecturer feedback
aligns with literature emphasising feedback as a social and dialogical process rather than a unidirectional transmission of
395 instructions (Pervin and Mokhtar, 2022; Escalante et al., 2023). In this context, lecturer–students interaction support not only
conceptual clarification but also the development of scientific communication skills, both verbal and written, which are core
graduate attributes in geology. At the same time, substantial minority (5/13) perceived AI-generated feedback as more readable
and detailed, consistent with findings reported by Escalante et al. (2023), suggesting that AI tools offer clarity, immediacy,
and elaboration in formative feedback. These findings point toward a complementary model in which AI-supported feedback
400 augments but does not replace lecturer judgement. Strategically integrating AI to provide preliminary or process-level



feedback, while preserving lecturer-led interpretive and higher-order feedback, optimises both efficiency and pedagogical depth. Thus, this study results reinforce that feedback in geology education must remain interactive, contextualised, and grounded in critical reasoning to effectively create analytical competence and professional communication.

5.4 Challenges and limitations

405 Despite positive performance outcomes, the identified implementation constraints carry significant implications for the geology curriculum regarding structured preparation for field-based learning. Resource limitations including the absence of dedicated laboratory facilities and curated sample collections, together with logistical challenges to fieldwork and limited staffing capacity, underscore the vulnerability of experiential components when institutional support is constrained. Given that geology is fundamentally an observational and interpretive science grounded in field evidence, inadequate preparation prior to field excursions risks reducing fieldwork to descriptive exposure rather than analytical engagement. Effective field learning 410 requires cognitive moulding including conceptual grounding, technical skill rehearsal, and clear learning objectives before venturing to the field (Argyilan et al., 2024; Dolphin et al., 2019). Pre-field preparations enhance student safety, optimise limited field time, and promote higher-order skills such as geological mapping, structural interpretation, and hypothesis testing. This is particularly critical for academically underprepared cohorts, where uneven knowledge affect spatial reasoning and 415 quantitative interpretation in the field. Thus, the findings of this study indicate the need for structured pre-field modules, simulated or laboratory-based preparatory exercises, and explicit skills benchmarking prior to field excursions. Such practices not only mitigate logistical risk but also strengthen the pedagogical integrity of fieldwork as a capstone integrative practice essential for geology graduates' competences.

An additional concern emerging from the implementation review was evidence of content overload, attributable to ambitious 420 syllabus coverage combined with students carrying multiple concurrent modules. While comprehensive exposure to geological subdisciplines is desirable, excessive breadth compromises depth of conceptual comprehension. This is paramount, especially in a cognitively geology field that requires integration of subdisciplines such as stratigraphy, mineralogy, structural geology, and geochemistry. Curriculum theory cautions against overloading novice students, as excessive content volume increases extraneous cognitive load and inhibits meaningful learning (Hristov et al., 2023). Within a geology curriculum, where concepts 425 such as deep time, three-dimensional visualisation, and process-based reasoning already present intrinsic complexity, overextension risks encouraging surface learning strategies focused on memorisation rather than analytical synthesis. The issue is compounded when students are simultaneously enrolled in multiple modules, limiting the time available for reflective practice, laboratory preparation, and consolidation of field observations. For curriculum refinement, these findings suggest the need for careful content prioritisation, explicit identification of core geology competencies, and vertical moulding across year 430 levels. Rationalising content to emphasise conceptual coherence over exhaustive coverage likely enhance retention, reduce cognitive strain, and better support the development of durable geological reasoning skills (Henríquez, 2025).



Fieldwork implementation was further constrained by logistical challenges, including safety, transport, equipment shortages, and occasional delays or cancellations. These disruptions have significant curricular implications because field-based instructions in geology are not supplementary but constitutive of geology programme. Fieldwork is widely recognised as a high-impact pedagogical practice in the field of geosciences, enabling students to integrate theoretical constructs with *in situ* observations, develop spatial reasoning, and create professional judgement under conditions of uncertainty (Argyilan et al., 2024; Dolphin et al., 2019). When logistical instability reduces field exposure, students experience fragmented learning and diminished opportunities for authentic problem-solving experiences. Moreover, safety and operational constraints necessitate risk management frameworks, clear field protocols, and adequate staffing ratios to maintain pedagogical quality while safeguarding students and lecturers. The results in this study show the need for strategic planning, secured institutional support, and contingency design such as preparatory simulations, virtual field tools, or staged local excursions to ensure continuity of experiential learning. Strengthening logistical infrastructure is therefore not merely an administrative concern but a prerequisite for sustaining the epistemological core of geology education.

3.5 Mitigation strategies

The involvement of industry experts in the delivery of selected components of the programme carries significant weight for curriculum relevance, authenticity, and graduate attribute attainment in geology. Geology is an applied profession in which technical competence, regulatory awareness, ethical practice, and multidisciplinary collaboration are central to employability (UNESCO, 2021; Pervin and Mokhtar, 2022). Industry experts were invited during the semester to contribute to teaching through guest lectures, site visits, and co-supervision of applied projects and assignments. This engagement strengthened constructive alignment by ensuring closer coherence between academic learning outcomes and workplace expectations (Freire, 2000; Shih, 2018; Rogers et al., 2022). Exposure to practising professionals enables students to engage with authentic problems and discourse characteristics of geology field. This collaboration enhances the development of graduate skills such as applied problem-solving, professional communication, ethical reasoning, and industry-standard technical reporting. It also assists students in understanding mineral exploration workflows, environmental compliance requirements, and risk assessment procedures within real regulatory and commercial contexts. Strategically embedding industry expertise therefore advances curriculum responsiveness, strengthens work-integrated learning pathways, and supports the training of graduates who are not only conceptually competent but professionally prepared for the geoscience sector.

6 Conclusions

Methodologically, this study operationalised constructive alignment through systematic curriculum implementation and iterative quality assurance processes, supported by consultations with industry and universities. The research adopted a qualitative approach, drawing on expert guidance, peer review inputs, students' evaluations and performance data. Although nonprobability purposive sampling limits generalisability, triangulation across multiple data sources enhance the credibility



and trustworthiness of the findings. These findings demonstrate that successful implementation of an undergraduate geology curriculum in a post-Covid19 higher education context depends on the deliberate alignment of geology epistemology, pedagogical theories, and institutional capacity. By integrating constructivist and transformative learning theories with hybrid teaching models, digital technologies, and carefully framed field and laboratory experiences, the curriculum meritoriously aided students' engagement, conceptual understanding, and practical competence despite infrastructural and staffing limitations. Imperative evidence from students' performance, peer review, and quality assurance processes indicates that flexible, inquiry driven, and contextually responsive approaches are capable of abating disparities in students' preparedness while maintaining academic integrity and professional relevance. Notably, the findings reinforce national regulatory frameworks efficiency when treated as enabling benchmarks rather than prescriptive protocols, creating space for innovation and responsiveness to local needs. Collectively, the study findings affirm the value of viewing geology curricula as a dynamic process capable of evolving through reflective practice, experts dialogue, and continuous evaluation, thereby enabling geology education to respond meaningfully to societal, environmental, and technological challenges in an increasingly uncertain global setting.

Despite expanding post Covid19 pedagogical scholarship, significant research gaps persist regarding longitudinal evidence on the effects of hybrid and AI supported curricula on graduate competence, employability, and professional practice in geology, necessitating the need for further research in these areas. Much of the existing evidence relies on short-term outcomes and perceptual data, with geology specific analyses often extrapolated from broader STEM contexts. Consequently, there is insufficient empirical attention to geology's distinctive spatial, interpretive, and field based epistemologies. Thus, curriculum innovation is required to intertwine with issues of equity, language, and epistemic access concerns that are particularly salient in South African universities, where historical inequalities impact students' preparedness and participation.

Data availability

The data sets used for this study can be made available from the corresponding author upon request. Interested parties wishing to replicate these data are invited to contact the authors for comprehensive details regarding the materials and resources utilised in this paper.

Author contributions

Lowanika V. Tibane: conceptualisation, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualisation, writing – original draft, writing – review and editing. **Clever Ndebele:** formal analysis, funding acquisition, resources, project administration, validation, writing – review and editing. Both authors contributed to the manuscript, read, and approved the final manuscript.



Competing interests

The corresponding author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

495 Ethical statement

This study was performed with consent from the dean of faculty, adhering to ethical guidelines. Any personal data collected was anonymised, and participation was voluntary, prioritising students' educational and safety protocols.

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