Assessing Students' Progress in Chemistry: Using Multiple-Choice Questions and Performance-Based Assessments

Juma'a Al-Kafawein[1,*] & Mohammed Al-Hilal[2]

[1]Department of Chemistry, King Faisal University, Al-Hassa, Saudi Arabia

[2]English Language Department, King Faisal University, Al-Hassa, Saudi Arabia

*Correspondence: Department of Chemistry, King Faisal University, Al-Hassa, Saudi Arabia

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Abstract

This article aims to investigate the progress of preparatory year students in a single-quarter chemistry course at King Faisal University, using multiple-choice questions (MCQs) and performance-based assessments. The article evaluates students' conceptual understanding and application of chemistry concepts, compares the effectiveness of these assessment methods, and identifies areas for instructional improvement. The results of MCQs showed significant improvement in conceptual understanding throughout the quarter, with average scores steadily increasing. Performance-based assessments, such as projects, demonstrated enhanced problem-solving and application skills, consistently producing higher scores than MCQs. Moreover, comparative analysis highlighted the complementary nature of these methods in evaluating students' proficiency. In addition, interviewing students provided additional insights and emphasized the importance of a balanced assessment approach. The study concludes that integrating traditional and performance-based assessments effectively captures students' progress in chemistry. Recommendations include diversifying assessment formats and using technology to increase evaluation practices. Future research should explore larger sample sizes and additional instructional contexts to refine assessment strategies.

Keywords: chemistry education, assessment methods, conceptual understanding, performance-based assessments

1. Introduction

Assessing students' progress and understanding is important in courses like chemistry, where mastering complex concepts and applying them in practical contexts are integral to learning. For preparatory year students studying chemistry for only one quarter during their foundational studies, it is essential to evaluate their understanding of key concepts and application skills within this limited timeframe. The effectiveness of assessment methods, therefore, plays a critical role in ensuring the course achieves its educational objectives (Bagban et al., 2017).

Traditional assessment tools, such as multiple-choice questions (MCQs), are widely recognized for efficiently evaluating students' conceptual understanding and providing immediate feedback (Appaji & Kulkarni, 2012). However, MCQs often fall short in assessing higher-order cognitive skills and practical application. To address these limitations, performance-based assessments, such as projects and experiments, are increasingly integrated into science education. These methods provide a more comprehensive evaluation by emphasizing creativity, problem-solving, and critical thinking (Colley, 2008).

This study focuses on preparatory year students at King Faisal University enrolled in a one-quarter chemistry course in the academic year 2023/24. By employing a combination of MCQs and performance-based assessments, the study aims to evaluate students' progress, identify strengths and weaknesses, and explore the effectiveness of these assessment methods. The study also seeks to understand students' perceptions of these tools, providing valuable insights for improving instructional and evaluative practices in similar educational contexts.

The challenges of assessing student progress in chemistry are not unique to King Faisal University. Globally, educators in STEM disciplines face the dual responsibility of ensuring foundational knowledge while cultivating higher-order thinking skills essential for problem-solving in real-world contexts (Rehmat & Hartley, 2020). Preparatory-year programs, in particular, play a critical role in bridging gaps between high school education and university-level expectations. Studies have shown that diverse assessment strategies are pivotal for promoting deep learning and

engaging students with varied academic backgrounds (Matos et al., 2023). By aligning assessment practices with global trends, such as integrating technology and performance-based evaluations, educators can better prepare students for the evolving demands of scientific and technological fields.

2. Objectives of the Study

1. To assess students' understanding of foundational chemistry concepts using MCQs.
2. To evaluate students' ability to apply chemistry knowledge through performance-based assessments, such as projects.
3. To compare the effectiveness of MCQs and performance-based assessments in measuring students' progress.
4. To provide actionable insights for improving assessment strategies within a one-quarter chemistry curriculum.

3. Literature Review

Performance-based assessments have gained significant attention as an alternative to traditional tools like multiple-choice questions (MCQs), particularly in contexts requiring the evaluation of higher-order cognitive skills (Liu, et al., 2023). Scully (2017) acknowledged that while MCQs are efficient for testing basic knowledge, their ability to measure skills such as analysis, synthesis, and evaluation is often limited. Although carefully constructed MCQs can assess higher-order thinking to some extent, the challenges involved in their design underscore the need for complementary assessment methods.

Performance-based assessments, which include tasks like projects and experiments, are particularly well-suited for evaluating critical thinking and problem-solving skills (Braun, et al., 2020). For instance, a study by Putri and Istiyono (2017) developed a performance assessment framework aimed at enhancing STEM-based critical thinking skills in high school physics lessons. Their research demonstrated that such assessments could effectively measure and improve students' critical thinking abilities within the STEM context.

Moreover, Kwarteng and Ahia (2023) found that performance-based assessments can significantly enhance creative thinking skills, particularly in science education. Their findings underscore the potential of such assessments to improve the quality of learning experiences, especially for pre-service teachers, by cultivating critical and creative thought processes.

These insights align with broader calls for reform in assessment strategies, suggesting that performance-based assessments represent a valuable complement to traditional tools like MCQs. By addressing the limitations of conventional methods, they provide educators with a robust framework for evaluating diverse cognitive and practical skills.

Fisher (1996) explored the effectiveness of combining performance-based and multiple-choice assessments to predict undergraduate success in mathematics and chemistry. The study examined the Algebra Diagnostic Test (ADT) at the University of California, within the context of the Hughes-Hallet calculus curriculum, which emphasizes problem-solving and task completion. Fisher developed a two-part test incorporating algebra, functions, proportions, and geometry, comparing its results to a traditional multiple-choice test. The findings revealed that while multiple-choice assessments had a higher correlation with course grades, combining both types of tests provided the most reliable predictions of student performance in calculus and chemistry.

Tüysüz (2009) developed a two-tier diagnostic instrument to identify misconceptions in ninth-grade chemistry students. Through a process involving interviews, item development, and testing with 141 students, a two-tier test with 15 questions was created. The results demonstrated that this diagnostic approach effectively identified misconceptions and offered a viable alternative to traditional multiple-choice tests for evaluating students' understanding and achievement.

Herrmann-Abell and DeBoer (2011) utilized distractor-driven multiple-choice assessments and Rasch modeling to examine middle to college-level students' understanding of chemistry concepts. Analyzing responses from over 13,000 students to 91 items, they identified hierarchies of misconceptions, with fewer misconceptions as overall performance increased. Additionally, Rasch modeling revealed structural flaws in some assessment items. This study underscored the utility of such tools in diagnosing learning progress and refining test quality.

Hartman and Lin (2011) analyzed student performance on 17 algorithmic multiple-choice questions in general chemistry. The study found a negative correlation between problem-solving steps required and the percentage of

students selecting the correct answer (PSCA). Variants of questions demonstrated the impact of algorithm complexity on student performance, suggesting that simplifying multi-step problems could improve outcomes.

Hudson and Treagust (2013) investigated the influence of assessment format (multiple-choice vs. short answer), question type (recall vs. application), and gender on student performance in chemistry exams. Analyzing university entrance and school exams over five years, supplemented with a test involving 192 students, the study used ANOVA and Rasch modeling. Results showed that students performed better on multiple-choice and recall questions, with male students outperforming females in higher scores. However, when ability levels were matched through Rasch modeling, gender differences were minimal. The study highlighted the importance of considering question difficulty and student ability in assessment evaluations.

Winarti and Mubarak (2019) employed Rasch modeling to evaluate the difficulty and quality of multiple-choice items in a chemistry test for high school students in Indonesia. Analyzing 20 questions on chemical bonding, they found the Rasch model effective for identifying item conformity and student answer patterns. The study emphasized the utility of Rasch modeling in guiding instructional design and evaluating student progress in chemistry education.

Shah, Fatima, Syed, and Glasser (2021) examined assessment practices and their impact on students perceived at risk of failure in general chemistry. Focusing on the performance of mathematically weaker students (GCI-S) versus their peers (GCI-M), the study revealed that quantitative execution questions contributed to performance disparities. However, at-risk students performed comparably on conceptual tasks such as comparing and predicting. The findings emphasized the need to diversify assessment strategies to promote equity in science education.

Williams, Wood, Arslantas, and MacNeil (2021) explored chemistry students' perceptions of multiple-choice assessments with varying feedback and partial credit systems. Their study highlighted the significance of feedback mechanisms in shaping student attitudes and learning outcomes, advocating for assessments that balance grading accuracy with constructive guidance.

To wrap up, these studies highlighted various aspects of assessing students' progress in chemistry, including the use of multiple-choice questions (MCQs), performance-based assessments, and diagnostic tools. However, most of these studies focused on specific contexts, such as high school, general undergraduate chemistry, or long-term curricula, leaving a gap in research addressing short-term, intensive courses like one-quarter preparatory chemistry programs. Additionally, while several studies compared the effectiveness of MCQs and alternative assessment methods, few integrated students' perceptions or explored how these tools can be combined to provide a comprehensive evaluation of conceptual understanding and practical application skills.

Moreover, studies examined performance in isolation (e.g., focusing solely on misconceptions, algorithmic problem-solving, or gender differences) rather than holistically analyzing the synergy between assessment formats. The unique context of preparatory-year students at King Faisal University, with its one-quarter chemistry course, offers an opportunity to address these gaps by exploring the combined effectiveness of MCQs and performance-based assessments while incorporating student feedback.

Another important aspect is the integration of technology into educational assessments which has gained significant attention over the past decade, offering opportunities to enhance traditional practices while addressing the challenges of modern learning environments. Many studies highlighted the role of technology in transforming assessment methods, with a focus on *Assessment for Learning* (AFL) and *Assessment of Learning* (AOL). By exploring diverse applications across various educational contexts, these studies underscore the potential of digital tools to foster student engagement, improve feedback mechanisms, and enhance learning outcomes.

DeLuca and McEwen (2010) explored the integration of technology to facilitate *Assessment for Learning* (AFL) in higher education, a strategy emphasizing continuous feedback, peer collaboration, and self-assessment. Their study focused on a pre-service teacher education course in Canada, where they paired technology with AFL practices to address challenges in large-group learning environments. The authors provided practical recommendations for improving web-based platforms and enhancing their alignment with AFL principles, underscoring the potential of technology to support instructional design and assessment processes.

Sweeney et al. (2017) conducted an extensive review of technology-enhanced assessment (TEA) in higher education, analyzing 139 articles out of 1,713 to assess its transformative potential. They found that TEA primarily supports formative peer learning through social media and feedback mechanisms, but evidence of significant improvements in student learning remains mixed. Their study advocated for further research to harness the full potential of TEA and foster a culture of inquiry in higher education.

Chan (2018) investigated teachers' perceptions of the role of technology in educational assessment within the context

of Macau. Through content analysis of responses from students in an educational evaluation course, the study revealed that teachers predominantly associate technology with *Assessment of Learning* rather than *Assessment for Learning*. The findings highlighted the need to provide educators with experiences and training that illustrate how technology can support instructional objectives.

Deeley (2018) evaluated how technological methods can enhance formative and summative assessment practices in higher education. Conducted at a Scottish university, the study examined the advantages and challenges of using technology to improve learning through feedback. Deeley argued that flexible and incremental adoption of technological tools can effectively align with existing assessment practices, facilitating deeper student engagement and understanding.

Polifka and Holme (2019) examined the usability of computer-based chemistry assessments that utilize interactive technologies to measure students' use of external representations. Their usability study emphasized the importance of ensuring that technological tools do not introduce extraneous factors affecting assessment accuracy. They concluded that testing and refining user interfaces are crucial for preventing errors and maintaining reliability in technology-driven assessments.

Budhai (2021) highlighted the transformative potential of digital tools in assessing student learning across various learning environments, including in-person, hybrid, and virtual classrooms. The book framed tools like polling, social media, and multimedia platforms as effective for conducting formative, summative, and self-paced assessments. It emphasized the role of technology in identifying learning gaps, modifying instruction, and disseminating assessment data to students, families, and administrators.

Ewim and Opateye (2021) explored the role of information and communication technology (ICT) in chemistry education, particularly during the COVID-19 pandemic. They emphasized that ICT tools enable continuous *Assessment for Learning* by providing feedback and diagnosing students' understanding during instruction. The study concluded that ICT-driven assessments could help educators adapt to remote learning contexts while maintaining effective feedback loops.

Mayo and Chua (2022) investigated innovative assessment techniques in an online distance learning context. The study involved Grade 8 chemistry students and assessed the impact of digital tools on their conceptual understanding and performance. Findings demonstrated significant improvement in students' understanding after exposure to feedback-driven, interactive assessment methods. The study highlighted the reliability and authenticity of innovative digital assessments in fostering meaningful learning experiences.

Safitri and Purnamasari (2024) conducted a systematic review to evaluate the effectiveness of digital evaluation tools in enhancing student engagement and performance. Their research revealed that digital tools, such as web-based assessments, increase students' interest and enthusiasm for learning. The authors emphasized the importance of updating evaluation methods to match technological advancements and proposed practical applications for lecturers to deliver interactive and engaging lessons.

While the reviewed studies emphasized the transformative potential of technology in assessments, many focused on broader or more traditional educational settings, often without addressing the specific challenges and needs of short-term, intensive courses such as preparatory-year chemistry programs. Additionally, while technology is widely discussed in terms of formative assessments and feedback, fewer studies examine the combined impact of multiple assessment methods (e.g., MCQs and performance-based tasks) in a single course context. This article uniquely contributes to the literature by exploring how technology-enhanced assessments can be effectively integrated into a one-quarter chemistry course for preparatory students, addressing the specific needs of this cohort and offering actionable recommendations for instructors in similar contexts.

4. Methodology

4.1 Study Design

This article used a mixed-methods approach to evaluate students' progress in a one-quarter chemistry course at King Faisal University. The research combined quantitative data from multiple-choice questions (MCQs) and performance-based assessments with qualitative insights from student interviews.

4.2 Participants

A sample of 100 preparatory year students was selected to represent a diverse cohort. The sample included:

- **Gender Balance**: 50 male and 50 female students.

- **Academic Backgrounds**: Students were stratified based on high school GPA:
    - 30 students with GPAs between 2.5–2.9.
    - 40 students with GPAs between 3.0–3.9.
    - 30 students with GPAs between 4.0–5.0.

4.3 Assessment Tools

1. **Multiple-Choice Questions (MCQs):**
    - Administered at the beginning, midpoint, and end of the quarter to measure students' conceptual understanding.
    - The questions covered core topics in chemistry, including atomic structure, chemical bonding, stoichiometry, and thermodynamics.
    - Results were analyzed to track improvements in conceptual understanding over the quarter.
2. **Performance-Based Assessments:**
    - Students completed projects aimed at evaluating their ability to apply chemistry knowledge in practical contexts.
    - The projects required students to design experiments, analyze data, and present their findings.
    - A rubric was used to assess the projects based on four criteria: understanding of chemical principles, creativity, experimental design, and clarity of presentation.

4.4 Data Collection and Analysis

The study employed a mixed-method approach, collecting both quantitative and qualitative data to comprehensively evaluate students' progress. Quantitative data included MCQ scores and performance-based assessment results, which were gathered throughout the quarter. These data were analyzed to identify trends in students' performance, pinpointing areas of strength and weakness. In addition, qualitative data were obtained through semi-structured interviews with a subset of students. These interviews explored students' experiences with MCQs and performance-based assessments, focusing on perceived challenges, strengths, and the impact of these methods on their learning.

For data analysis, quantitative results from MCQs were examined for performance trends, with mean scores and score ranges compared across assessment periods. Performance-based assessment scores were analyzed using descriptive statistics to uncover patterns in students' application skills. The qualitative data were subjected to thematic analysis, which provided a deeper understanding of students' perceptions of the assessment methods, highlighting their effectiveness and suggesting areas for improvement. Together, these analyses offered a holistic view of students' progress and the role of assessment tools in fostering conceptual understanding and practical application.

5. Results and Discussion

The results of the study revealed significant progress in students' conceptual understanding and application of chemistry concepts during the one-quarter course. Quantitative data from MCQs and performance-based assessments, as well as qualitative feedback from interviews, provided a comprehensive picture of student learning.

5.1 Quantitative Results

Table 1. MCQ Performance Across the Quarter

Assessment Period	Average Score (%)	Score Range (%)
Beginning of Quarter	48	27–77
Midpoint of Quarter	69	49–86
End of Quarter	79	53–98

According to Table 1, average MCQ scores improved by 31 percentage points from the beginning to the end of the quarter, demonstrating a significant enhancement in students' conceptual understanding. The narrowing of the score range further suggests that students achieved more consistent performance levels as the course progressed. Analysis of core topics revealed that students showed strong understanding in areas such as atomic structure and stoichiometry,

while topics like thermodynamics and organic chemistry remained more challenging, indicating potential areas for targeted instructional improvement.

Table 2. Performance-Based Assessment Results

Project	Average Score (%)	Key Strengths	Key Weaknesses
Project 1 (Midpoint)	78	Alignment with theoretical concepts, creativity	Data interpretation and presentation clarity
Project 2 (End of Quarter)	88	Experimental design, critical thinking, originality	Minor issues in report organization

It is clear from the results in Table 2 that performance-based assessments exhibited steady progress, with average scores increasing by 10 percentage points between the first and second projects. This improvement reflects students' growing proficiency in designing experiments, analyzing data, and effectively communicating their findings. However, challenges were noted, particularly in the initial project, where students struggled with data analysis and presenting their findings clearly, highlighting areas for further instructional focus.

5.2 Comparison of Assessment Methods

Table 3. Average Scores Comparison

Assessment Type	Midpoint Average (%)	End of Quarter Average (%)
MCQs	69	79
Performance Assessments	78	88

According to Table 3, both assessment methods demonstrated significant improvement over the course of the quarter, indicating the effectiveness of the instructional strategies and high levels of student engagement. Notably, performance-based assessments consistently produced higher scores than MCQs, suggesting that students exhibited stronger practical application skills compared to their ability to recall theoretical concepts.

The findings also highlighted an opportunity to leverage technology for enhancing assessment practices. Online platforms providing interactive quizzes can transform MCQs into adaptive learning tools that cater to individual student needs. For instance, questions could dynamically adjust their difficulty based on the student's performance, ensuring an appropriate level of challenge while providing immediate feedback.

In performance-based assessments, technology can play a transformative role. Virtual laboratories, such as JoVE or ChemCollective, offer safe and accessible environments for students to simulate experiments, analyze results, and present findings. These tools are particularly beneficial for preparatory programs, where time and resources for physical experiments may be limited. Additionally, incorporating multimedia components, like video presentations or digital posters, can enhance the evaluation of students' communication skills.

Another promising avenue is the use of data analytics to track student progress. Learning management systems (LMS) equipped with analytics dashboards can provide instructors with insights into individual and class-wide performance trends, enabling more targeted interventions.

5.3 Qualitative Insights from Student Interviews

The thematic analysis revealed several key insights into students' experiences with the assessment methods. MCQs were regarded as effective for reinforcing foundational concepts and identifying knowledge gaps, with their format providing immediate feedback that supported targeted studying. Performance-based assessments, on the other hand, were highly valued for fostering creativity and critical thinking, allowing students to apply theoretical knowledge in practical contexts and deepening their understanding of real-world applications. However, challenges were noted in both methods; MCQs were perceived as limited in assessing complex reasoning and higher-order thinking, while performance-based assessments highlighted difficulties in data analysis and report writing, indicating areas for further instructional support.

The results highlighted the strengths and weaknesses of the two assessment methods used in the study. MCQs proved effective in evaluating students' conceptual understanding and providing a standardized measure of knowledge. High performance in topics like atomic structure and stoichiometry suggests alignment with students' prior knowledge, reinforcing their foundational understanding. Performance-based assessments, meanwhile, encouraged creative and

critical application of knowledge, with notable improvements observed in students' experimental design and data interpretation skills, demonstrating their effectiveness in fostering deeper learning. However, challenges persist; difficulties in thermodynamics and organic chemistry point to the need for enhanced instructional strategies, while students' struggles with data analysis and presentation skills in projects underscore the importance of providing additional support in these areas.

The findings showed the complementary nature of MCQs and performance-based assessments in evaluating student learning. While MCQs effectively measured theoretical understanding, performance-based assessments captured students' ability to apply knowledge in practical settings. Together, these methods provided a balanced and comprehensive evaluation of student progress.

The qualitative insights gained from interviewing students underscore the importance of personalized and practical assessment approaches. One student remarked, *"The MCQs were helpful for quick review, but I felt the projects pushed me to think more deeply and apply what I learned."* Another shared, *"I struggled with presenting data clearly in the first project, but the feedback helped me improve significantly for the second one."* These reflections highlight the complementary strengths of MCQs and performance-based assessments in addressing different aspects of learning.

Moreover, the interviews revealed specific challenges. Several students noted difficulty grasping complex topics like thermodynamics through MCQs alone, suggesting the need for supplemental instructional tools. Similarly, while performance tasks encouraged creativity, some students struggled with balancing theoretical accuracy and practical execution. These insights emphasize the need for continuous feedback and targeted support to maximize the effectiveness of both assessment methods.

To wrap up, the study assessed students' understanding of foundational chemistry concepts using multiple-choice questions (MCQs) and evaluated their ability to apply chemistry knowledge through performance-based assessments. The results showed that MCQs effectively measured students' conceptual understanding, with significant improvement in scores over the quarter, especially in core topics like atomic structure and stoichiometry. Performance-based assessments, such as projects, allowed students to demonstrate their ability to apply theoretical knowledge in practical contexts, with notable improvement in skills like experimental design, data analysis, and communication. Comparing the two methods revealed that while MCQs were effective in assessing theoretical knowledge, performance-based assessments provided a better measure of students' practical application and critical thinking skills. Both assessment methods showed significant improvement, suggesting that a combination of MCQs and performance-based assessments is the most effective approach for evaluating students' progress. The findings provide actionable insights for improving assessment strategies, such as diversifying assessment formats and enhancing feedback mechanisms to support continuous student growth within the one-quarter chemistry curriculum.

6. Conclusion

This study evaluated the progress of preparatory year students in a one-quarter chemistry course using multiple-choice questions (MCQs) and performance-based assessments. The findings revealed significant improvement in both conceptual understanding and application of chemistry concepts over the course of the quarter.

MCQs effectively assessed foundational knowledge and identified areas requiring additional focus, while performance-based assessments provided deeper insights into students' problem-solving, critical thinking, and practical application skills. The complementary nature of these methods underscores the importance of using a balanced approach to capture the multifaceted aspects of student learning.

Despite these positive outcomes, challenges such as difficulty with data analysis, report clarity, and specific conceptual topics (e.g., thermodynamics and organic chemistry) highlight areas for instructional and assessment enhancement. The insights gained from this research provide valuable guidance for educators, curriculum designers, and policymakers to refine teaching and assessment strategies for short-term science courses like this one-quarter chemistry curriculum.

Based on the study findings, several recommendations are proposed to enhance chemistry education and assessment. These include diversifying assessment methods by incorporating oral presentations, laboratory reports, and peer assessments to provide a comprehensive evaluation of students' skills. Enhancing feedback mechanisms through timely and detailed feedback will help students address weaknesses, particularly in data analysis and presentation skills. Targeted interventions, such as supplemental tutorials and interactive simulations, should be introduced to address persistent challenges in topics like thermodynamics and organic chemistry. Additionally, leveraging technology in assessment, such as using online platforms for MCQs and virtual labs for performance-based

assessments, can enhance both practicality and accessibility. Supporting practical application skills in project-based assessments with structured guidance will help students improve experimental design and data interpretation. Finally, expanding research to include larger, more diverse student populations can provide broader insights into effective assessment practices. Implementing these recommendations will foster deeper learning and better prepare students for success in chemistry and related fields.

Building on the findings of this study, future research could explore several promising directions. One area is longitudinal studies that examine the long-term impact of balanced assessment methods on students' academic performance in subsequent chemistry courses or other STEM disciplines. Such research would provide valuable evidence of the sustainability and scalability of the proposed strategies.

Another critical direction involves investigating the role of demographic factors, such as gender, socioeconomic background, and prior academic preparation, in shaping student performance. By identifying patterns and potential disparities, educators can develop more equitable assessment strategies that address the diverse needs of their student populations.

Expanding the study to include a larger and more diverse sample is also essential. Research conducted across multiple institutions with varying curricular structures can validate the findings and provide a broader understanding of effective assessment practices. Moreover, exploring interdisciplinary contexts, where chemistry concepts are applied in fields like biology or engineering, could shed light on how assessments can be tailored to support cross-disciplinary learning.

Finally, future studies could examine the integration of emerging technologies, such as artificial intelligence (AI) and machine learning, in designing assessments that are both adaptive and engaging. For example, AI-powered tools could analyze student responses to open-ended questions, providing instant feedback while promoting critical thinking skills.

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