# REIMAGINING CHEMISTRY CLASSROOMS: A CASE FOR THE INQUIRY CYCLE MODEL IN 21ST CENTURY EDUCATION

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**Abstract:** *This paper advocates for a paradigm shift in secondary school chemistry instruction through the adoption of the Inquiry Cycle Model (ICM). Traditional approaches to chemistry education in many schools continue to rely heavily on rote memorisation and passive learning, limiting students' ability to engage critically with scientific concepts and practices. In response to this challenge, the ICM offers a structured yet flexible framework that mirrors authentic scientific inquiry. It engages students in iterative cycles of questioning, hypothesis formulation, investigation, data interpretation, conclusion drawing, and reflective discussion. This process not only deepens conceptual understanding but also fosters essential process skills such as critical thinking, experimentation, and scientific communication. The model's cyclical nature allows learners to revisit and refine their understanding, better preparing them for modern scientific careers and civic responsibilities. The paper explores the pedagogical, curricular, and infrastructural benefits of implementing the ICM, while acknowledging the practical challenges such as teacher readiness, time constraints, and resource availability. Recommendations are offered for systemic adoption, teacher professional development, curriculum reform, and assessment realignment to support sustainable implementation. Ultimately, the paper argues that the Inquiry Cycle Model presents a scalable and effective solution to enhance chemistry education, aligning instructional practices with the demands of the 21st century and promoting scientific literacy among students.*

**Keywords:** *chemistry education; inquiry cycle model; instructional reform; scientific process skills; student-centered learning.*

## Introduction

### A. The Current State of Chemistry Education

Chemistry, as a core science subject, plays a crucial role in helping students understand the world around them and in developing their scientific reasoning skills. It is defined as the study of composition, properties, uses and changes that matter undergoes. It is widely regarded as the foundation of science and technology, earning its title as the *"central science"* (Nicol et al., 2024). Given its role as a catalyst for sustainable growth (Adewumi & Monisola, 2013), it's crucial to enhance teaching methods in chemistry, especially in secondary schools, where foundational knowledge is established. This will help students develop the essential competencies needed to drive progress in science and technology (Hauspie et al., 2023)

However, in many secondary schools, chemistry is still taught using approaches that focus mainly on memorisation of facts, while students remain passive recipients of information (Nakum, 2022; Ojo, 2017). This approach does not allow learners to engage fully with the subject or to develop important scientific skills such as problem-solving, critical thinking, and experimentation (Muhammad et al., 2021; Tijani, 2025b). Furthermore, these approaches produce both active and passive learners, prioritising the teacher's role and immediate context over learner engagement, which limits active involvement in the learning process (Khalaf, 2018; White et al., 2015).

The persistence of these traditional methodologies has created a generation of chemistry students who can recite formulas and definitions but struggle to apply their knowledge to real-world problems or engage in authentic scientific reasoning. Students often view chemistry as a collection of abstract concepts disconnected from their daily experiences, leading to decreased interest in pursuing science-related careers and limiting their scientific literacy as future citizens.

### B. The Need for Reform

The demands of the 21st century require citizens who can think critically, solve complex problems, and make informed decisions based on scientific evidence. In chemistry education, this translates to the need for instructional approaches that mirror authentic scientific practice, where students actively investigate phenomena, formulate hypotheses, design experiments, and communicate findings. The current educational paradigm fails to meet these demands, creating a significant gap between what students learn and what they need to succeed in higher education, careers, and civic life (Bybee, 2013; James et al., 2024).

Moreover, national examination systems such as the West African Examination Council (WAEC) and National Examination Council (NECO) increasingly emphasize practical competencies and process skills in their assessments. Students are expected to demonstrate not only conceptual understanding but also the ability to design experiments, interpret data, and draw evidence-based conclusions. The traditional lecture-and-memorization approach leaves students ill-prepared for these expectations, resulting in poor performance and limited understanding of chemistry's practical applications.

### C. Position Statement

To address these challenges in chemistry education, many educators advocate for inquiry-based learning (IBL) approaches that shift the learning process from passive reception to active exploration. IBL encourages students to participate in the construction of knowledge by engaging in activities such as asking questions, formulating hypotheses, designing investigations, gathering data, and drawing evidence-based conclusions (Annisa & Rohaeti, 2018; Omovie & Eravwoke-Agboro, 2023; Tijani, 2025a). These practices help students develop scientific reasoning, enhance critical thinking, and foster a deeper understanding of core scientific concepts (Owolade et al., 2022).

Among the structured models of inquiry-based learning, the Inquiry Cycle Model (ICM) stands out for its emphasis on iterative exploration and reflective learning. Unlike fully open inquiry, which, although highly student-centered, can overwhelm learners without sufficient structure, the ICM offers a guided yet flexible approach that balances student autonomy with teacher scaffolding (Pedaste et al., 2015; Bruce & Casey, 2012). This model allows students to engage meaningfully in scientific practices while ensuring that learning objectives are met in a coherent, manageable way.

The importance of structured inquiry like the ICM lies in its capacity to engage students in complex problem-solving scenarios, while also providing a defined framework that promotes higher-order thinking, systematic experimentation, and critical reflection (Porritt et al., 2022; Scanlon et al., 2011). This structured inquiry empowers learners to take responsibility for their investigations without the cognitive overload that often accompanies open-ended inquiry (Akuma & Callaghan, 2018). Moreover, students who engage in such guided models demonstrate improved retention, scientific literacy, and motivation compared to those exposed to traditional direct instruction or entirely unstructured inquiry (Zion & Slezak, 2005; Justice et al., 2002).

The role of the teacher in the ICM is to facilitate rather than direct learning, helping students frame investigable questions, plan experiments, analyze data, and communicate their findings. Scaffolding provided at key stages of the inquiry process helps learners maintain direction and develop confidence (White & Frederiksen, 1998). This position paper, therefore, argues for the systematic adoption of the ICM as the primary instructional framework in chemistry classrooms. The ICM offers a cyclical, student-centered approach that mirrors authentic scientific inquiry and supports the development of essential 21st-century competencies. Implementing the ICM in secondary education will transform chemistry instruction from rote memorization into an active, reflective, and skill-rich learning experience, better preparing students for academic success, scientific careers, and civic engagement.

## 1. The Inquiry Cycle Model: A Superior Framework

The Inquiry Cycle Model emphasizes the continuous refinement of knowledge through repeated cycles of questioning, investigation, and reflection, making it particularly well-suited for scientific problem-solving and student-led inquiry (Porritt et al., 2022). Unlike the 7E Model, which follows a stepwise progression, the Inquiry Cycle Model encourages students to revisit and adjust their approaches based on experimental outcomes, fostering deeper critical thinking and adaptability. This model reinforces the cyclical nature of scientific inquiry, where students formulate questions, investigate problems, analyze data, and refine their understanding through repeated cycles of exploration.

The superiority of the ICM lies in its authentic representation of how science actually works. Real scientific discoveries rarely follow a linear path; instead, they involve iterative cycles of hypothesis formation, testing, revision, and retesting. By structuring learning around these natural cycles, the ICM prepares students for authentic scientific practice while developing their capacity for adaptive thinking and problem-solving. Pedaste et al. (2015) developed a comprehensive framework for inquiry-based learning and found that integrating cyclical stages of Orientation, Conceptualization, Investigation, Conclusion, and Discussion, as presented in Table 1 below.

**Table 1:** *Stages of the Inquiry Cycle Model and Their Descriptions*

| Stage | Description | Key Sub-phases / Features |
|---|---|---|
| Orientation | Students are introduced to a real-world problem or phenomenon that captures interest and triggers curiosity. They observe | - Engagement with context.<br>- Problem recognition. |

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| | and identify the main problem that needs investigation. | |
| Conceptualization | Students formulate investigable questions and hypotheses to guide their inquiry. They analyze the situation and plan how to explore it. | - Questioning: Formulating relevant and investigable questions (White & Frederiksen, 1998).<br>- Hypothesis generation: Developing testable predictions (De Jong, 2006). |
| Investigation | Students design and conduct experiments, make observations, collect data, and explore relationships between variables to test their hypotheses. | - Exploration: Systematic investigation without rigid hypotheses (Lim, 2004).<br>- Experimentation: Controlling variables and collecting data (De Jong, 2006).<br>- Data Interpretation: Synthesizing results and deriving meaning (Bruce & Casey, 2012). |
| Conclusion | Students analyze results in comparison with hypotheses, interpret data, and draw conclusions that explain observed patterns and address the research questions. | - Critical analysis and synthesis.<br>- Reasoning based on evidence (Scanlon et al., 2011; White et al., 1999). |
| Discussion | Students present their findings, receive feedback, reflect on their process, and connect their learning to real-world applications or further inquiry. | - Communication: Sharing findings (Bruce & Casey, 2012).<br>- Reflection: Justifying methods, evaluating outcomes, proposing improvements |

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|---|---|
| | (Pedaste et al., 2015; Lim, 2004). |

The first stage of the Inquiry Cycle Model is *"orientation"* (Table 1). This stage is where students are introduced to a problem, scenario, or phenomenon that captures their interest and motivates them to investigate further (Pedaste et al., 2015). During this stage, students carefully observe the situation presented, identify the main problem, and begin to think about possible questions they may wish to explore. The main aim of this stage is to help students recognize that there is a problem that requires investigation and to spark their curiosity about solving it.

The second stage of the inquiry process, as shown in Table 1, is *"conceptualization"*, where students think deeply about the problem they observed during the orientation stage, asking specific questions and developing hypotheses or predictions about potential outcomes. This stage involves critical thinking and planning as students decide how to explore their questions through experimentation. cConceptualization consists of two key sub-phases: *questioning*, which involves formulating investigable questions (White & Frederiksen, 1998), and *hypothesis generation*, which entails developing testable hypotheses (De Jong, 2006). By formulating research questions and hypotheses, students set the stage for a well-structured investigation, enabling them to think deeply about the problem and develop a plan for exploration (Pedaste et al., 2015). Effective conceptualization is crucial for guiding the investigation and ensuring that students' inquiries are focused and productive.

As presented in Table 1, the third stage of the scientific process is *"investigation,"* where students design and conduct experiments to test their hypotheses and collect data (Pedaste et al., 2015). This hands-on stage involves using scientific tools, materials, and methods to gather information and make observations. Investigation consists of three key sub-phases: *exploration, experimentation*, and *data interpretation* (De Jong, 2006; Lim, 2004; Scanlon et al., 2011; White & Frederiksen, 2005). During exploration, students systematically investigate relationships between variables, often without a stated hypothesis, but with careful planning to optimize resources. Experimentation involves developing a strategic plan to test a hypothesis, defining variables to be controlled or varied, and collecting evidence to support or refute the hypothesis. Data interpretation enables students to extract meaningful insights from collected data, synthesize new knowledge, and formulate relationships between variables (Bruce & Casey, 2012; Justice et al., 2002; Lim, 2004; White & Frederiksen, 1998; Wilhelm & Walters, 2006). By engaging in these sub-phases, students directly participate in the scientific process, fostering critical thinking, problem-solving, and analytical skills.

After completing their investigations, students move on to the fourth stage, *"conclusion,"* as shown in Table 1. In this stage, students analyze their findings in detail, compare the results with their original predictions, and draw conclusions based on the evidence they collected. They reflect on whether their hypotheses were correct and what scientific principles can explain their results, addressing their original research questions or hypotheses (De Jong, 2006; Scanlon et al., 2011; White et al., 1999). This stage enables students to synthesize information, make meaningful connections between their findings and scientific concepts, and potentially gain new theoretical insights. The outcome of this phase is a conclusion about the findings, providing a clear response to the research questions or hypotheses and solidifying students' understanding of the scientific principles involved.

As presented in Table 1, the final stage of the Inquiry Cycle Model is "*discussion,*" where students share their results with others through presentations, reports, or group discussions, receiving feedback and articulating their understandings (Bruce & Casey, 2012; Scanlon et al., 2011). This stage involves two key sub-phases: communication, where students present their findings, and reflection, where they evaluate the inquiry process, identify challenges, and propose improvements (Lim, 2004; White & Frederiksen, 1998). Through reflection, students can reach specific levels of quality, including description, justification, critique, and discussion (Pedaste et al., 2015), ultimately improving their communication skills, encouraging collaboration, and relating their findings to real-world problems or future investigations.

## Benefits and Advantages of ICM Implementation

### A. Student-Centered Benefits

Implementing ICM in chemistry education produces profound benefits for student learning and development. Most significantly, students develop authentic scientific process skills that extend far beyond chemistry content knowledge. Through repeated engagement with the ICM stages, students become proficient in formulating testable questions, designing controlled experiments, collecting and analyzing data systematically, and drawing evidence-based conclusions (Pedaste et al., 2015; Bruce & Casey, 2012; Justice et al., 2002). These skills are transferable to other scientific disciplines and to problem-solving in everyday life.

Students who participate in ICM-based instruction demonstrate enhanced critical thinking and analytical abilities. Rather than accepting information passively, they learn to evaluate evidence critically, consider alternative explanations, and recognize the limitations of their conclusions (Zion & Slezak, 2005; White & Frederiksen, 2005). This intellectual development produces students who are better prepared for the demands of higher education and professional careers, where independent thinking and problem-solving are essential.

The student-centered nature of ICM instruction dramatically increases motivation and engagement with chemistry. When students have ownership over their investigations and can pursue questions that genuinely interest them, they develop intrinsic motivation to learn (Onyema et al., 2019). This engagement is particularly important in chemistry, where traditional instruction often produces anxiety and disinterest. Students who experience success in ICM-based classrooms develop positive attitudes toward science and increased confidence in their ability to understand complex phenomena.

ICM implementation also helps students develop essential scientific communication skills as they regularly present their findings, defend their conclusions, and collaborate with peers. These communication experiences prepare students for the collaborative nature of modern scientific work while developing the presentation and writing skills that are valued in all professional contexts. Students learn to use appropriate scientific terminology, create effective visual representations of data, and engage in constructive scientific discourse (Scanlon et al., 2011; Lim, 2004).

**B. Pedagogical Advantages**

From a teaching perspective, ICM implementation transforms the classroom dynamic in ways that benefit both students and teachers. The model provides multiple opportunities for authentic assessment, where teachers can observe student thinking processes directly rather than relying solely on traditional tests and quizzes (Justice et al., 2002; Pedaste et al., 2015). Formative assessment becomes integrated naturally into the inquiry process as teachers observe student questioning, experimental design, data interpretation, and reflection activities.

Additionally, ICM instruction accommodates differentiated learning pathways that meet the needs of diverse learners. While all students engage with the same fundamental inquiry process, they can pursue investigations at different levels of complexity, focus on different aspects of problems, and demonstrate their understanding through various formats (Pedaste et al., 2015). This flexibility allows teachers to support struggling learners while challenging advanced students, creating inclusive learning environments where all students can succeed.

The integration of theory and practice inherent in ICM instruction helps students develop a coherent understanding rather than fragmented knowledge. Instead of learning concepts in isolation and then applying them in separate laboratory sessions, students construct theoretical understanding through their investigations (Justice et al., 2002; Scanlon et al., 2011). This integrated approach produces deeper, more durable learning that students can apply flexibly in new contexts.

### C. Curricular Benefits

The implementation of ICM-based instruction aligns naturally with national examination requirements that increasingly emphasize process skills and practical competencies. Students who have experience designing experiments, interpreting data, and drawing conclusions are well-prepared for practical examinations and coursework requirements (Justice et al., 2002; Pedaste et al., 2015). The authentic nature of ICM activities provides excellent preparation for the kinds of open-ended problems that appear on advanced placement and university entrance examinations.

The ICM framework facilitates integration across chemistry topics, helping students recognize connections between different areas of the subject. For example, students might investigate acid-base equilibria in one cycle, then later explore how buffer systems relate to biological processes, creating meaningful connections between apparently separate topics (Bruce & Casey, 2012; Scanlon et al., 2011). This integrated approach produces a more coherent understanding and helps students appreciate the unity of chemical principles.

Students who experience ICM-based instruction are better prepared for higher education and scientific careers. They enter university chemistry courses with experience in independent investigation, collaborative problem-solving, and scientific communication (Wilhelm & Walters, 2006; Zion & Slezak, 2005). These students are more likely to succeed in research experiences, laboratory courses, and graduate programs because they have already developed the thinking habits and practical skills that characterize successful scientists.

The ICM approach also develops essential 21st-century competencies that extend beyond chemistry knowledge. Students learn to work collaboratively, think critically about complex problems, communicate effectively with diverse audiences, and adapt to changing circumstances (Onyema et al., 2019; Bruce & Casey, 2012). These competencies are increasingly recognized as essential for success in the modern economy, where workers must be able to learn continuously and solve novel problems (Norris & Phillips, 2003).

## Challenges of Implementing ICM

### A. Teacher Preparation and Support

The successful implementation of ICM-based chemistry instruction requires comprehensive teacher preparation and ongoing support systems. Many chemistry teachers have limited experience with inquiry-based instruction, having been trained in traditional lecture-based methods and having taught using textbook-centered approaches for years (Akuma & Callaghan, 2018; DiBiase & McDonald, 2015). The transition to ICM requires fundamental shifts in teaching philosophy, classroom management strategies, and content delivery methods.

Professional development programs must address both the theoretical foundations of inquiry learning and the practical skills needed for ICM implementation. Teachers need to understand how students construct knowledge through investigation, how to facilitate rather than direct learning, and how to assess process skills as well as content understanding (Gholam, 2019; Pedaste et al., 2015). They must learn to ask questions that promote thinking rather than elicit specific answers, and to resist the urge to provide premature explanations that short-circuit student inquiry (White & Frederiksen, 2005).

Practical training should include hands-on experience with ICM activities from the student perspective, allowing teachers to understand the cognitive demands and emotional experiences of inquiry learning. Teachers need time to practice facilitating each stage of the inquiry cycle, learning to recognize when students need scaffolding and when they should be allowed to struggle productively with challenging problems (Justice et al., 2002).

Collaborative planning and resource sharing are essential for supporting ICM implementation. Teachers benefit from working in professional learning communities where they can share successful activities, troubleshoot implementation challenges, and collectively develop curriculum materials (Bell et al., 2005). Online platforms and regional networks can facilitate resource sharing and provide ongoing support for teachers as they develop their ICM expertise.

### B. Resource and Infrastructure Considerations

ICM implementation requires significant attention to laboratory equipment, materials, and physical space. Unlike traditional chemistry instruction, where students follow predetermined procedures using standard equipment, ICM requires flexible laboratory setups that can accommodate student-designed investigations (Pedaste et al., 2015). This means having a wide variety of equipment available, sufficient quantities of consumable materials, and laboratory spaces that can be reconfigured for different types of investigations.

Schools must invest in appropriate measuring instruments, including precision balances, pH meters, spectrophotometers, and data collection systems that allow students to make accurate measurements and collect reliable data. While expensive, these instruments are essential for authentic scientific investigation and help students develop the technical skills they will need in advanced courses and careers.

Time allocation presents another significant challenge for ICM implementation. Traditional chemistry courses are often structured around daily 50-minute periods that allow time for lecture and brief activities, but are insufficient for complete inquiry cycles. ICM requires extended time blocks that allow students to design investigations, collect data, analyze results, and engage in meaningful reflection (Bybee, 2013). Schools may need to adopt block scheduling or create extended laboratory periods to accommodate ICM instruction effectively.

Safety protocols require careful attention in ICM classrooms where students design their own investigations rather than following predetermined procedures. Teachers must establish clear safety guidelines while still allowing student creativity and independence (Kelley & Knowles, 2016). This requires extensive safety training for both teachers and students, appropriate safety equipment, and clear protocols for reviewing student experimental designs before implementation.

Technology integration can enhance ICM implementation by providing tools for data collection, analysis, and communication. Digital sensors can provide real-time data collection, computer simulations can allow investigation of phenomena that are too dangerous or expensive to study directly, and online platforms can facilitate collaboration and resource sharing. However, technology should enhance rather than replace hands-on investigation and direct observation of chemical phenomena (Bruce & Casey, 2012).

### C. Assessment and Evaluation

Assessment in ICM-based classrooms requires fundamental rethinking of evaluation strategies and criteria. Traditional tests that emphasize factual recall and algorithmic problem-solving are insufficient for evaluating the complex learning that occurs through inquiry. ICM assessment must capture student growth in process skills, conceptual understanding, and scientific reasoning abilities (White & Frederiksen, 2005; Scanlon et al., 2011)..

Developing appropriate assessment rubrics is essential for evaluating student progress in ICM classrooms. These rubrics must clearly articulate expectations for each stage of the inquiry cycle, providing specific criteria for evaluating question formulation, experimental design, data collection and analysis, conclusion drawing, and scientific communication (Bell et al., 2005). Rubrics should be developmental, showing progression from novice to expert performance and helping students understand how to improve their inquiry skills.

Balancing formative and summative evaluation is crucial in ICM assessment. The inquiry process naturally provides multiple opportunities for formative assessment as teachers observe student thinking and provide feedback during investigations. This ongoing feedback helps students improve their inquiry skills while building toward summative evaluations that capture overall achievement. Portfolio systems can effectively combine formative and summative assessment by documenting student growth over time (Justice et al., 2002).

Documenting process skill development requires systematic approaches to data collection and analysis. Teachers need strategies for observing and recording student progress in areas such as question formulation, experimental design, collaboration, and scientific communication. This documentation can include observation checklists, video recordings of student discussions, analysis of laboratory notebooks, and peer evaluation activities.

Alignment with standardized testing presents ongoing challenges for ICM assessment. While ICM instruction prepares students well for performance-based assessments and practical examinations, traditional multiple-choice tests may not fully capture the benefits of inquiry learning. Schools implementing ICM must work to educate stakeholders about the benefits of authentic assessment while ensuring that students are also prepared for required standardized assessments.

## Conclusion

The transformation of chemistry education in secondary schools is not only desirable but essential in the 21st-century knowledge economy. The traditional lecture-based, content-heavy instructional paradigm no longer meets the demands of a world that requires critical thinkers, problem solvers, and scientifically literate citizens. While inquiry-based learning has gained traction, its most student-centered form, open inquiry, poses implementation challenges that limit its practical adoption in mainstream classrooms.

The Inquiry Cycle Model (ICM) offers a research-based, practical, and scalable framework that balances structure with student autonomy. It supports the development of both conceptual knowledge and essential scientific process skills such as hypothesis generation, experimental design, data analysis, and scientific communication. Moreover, the cyclical nature of the ICM fosters deeper engagement, intrinsic motivation, and sustained understanding among students.

ICM also provides clear pedagogical advantages by enabling formative assessment, differentiated learning, and collaborative classroom culture. It aligns with current curriculum reforms and examination standards that emphasize scientific reasoning and performance-based competencies. With proper teacher preparation, administrative support, and resource allocation, the ICM can serve as a catalyst for meaningful and lasting educational reform.

**Recommendations**

In light of the evidence presented and the pressing need for reform in chemistry education, the following recommendations are proposed to guide the effective and sustainable implementation of the Inquiry Cycle Model:

I. **System-wide Adoption:** Educational stakeholders should priorities the systematic adoption of ICM as the core instructional framework for secondary school chemistry education. Pilot programs should be initiated in diverse school contexts to refine implementation and generate scalable models of success.

II. **Teacher Preparation and Professional Development:** Pre-service and in-service chemistry teachers must receive comprehensive training in ICM pedagogy. This includes theoretical foundations, hands-on facilitation skills, activity design, classroom management for inquiry, and strategies for authentic assessment.

III. **Curriculum Alignment:** National and state curriculum standards should be revised to incorporate inquiry-based outcomes, with specific reference to ICM processes. These standards should promote the integration of content knowledge and scientific practices.

IV. **Assessment Reform:** Examination bodies and assessment frameworks should transition toward performance-based tasks that evaluate process skills and conceptual understanding in line with ICM. This includes laboratory-based practical’s, open-ended investigations, and project-based assessments.

V. **Resource Allocation and Infrastructure Support:** Governments, educational authorities, and school administrators should provide adequate funding and support for laboratory facilities, modern science equipment, flexible class schedules, and digital technologies that facilitate ICM implementation.

VI. **Stakeholder Engagement:** Awareness campaigns and policy dialogues should be conducted to educate parents, school leaders, and policymakers about the long-term value of inquiry-based learning. Their understanding and support are essential for institutional and cultural acceptance of ICM.

VII. **Ongoing Research and Evaluation:** Continuous monitoring, research, and impact assessment should be carried out by educational institutions and research bodies to ensure that ICM practices are effectively improving learning outcomes and to inform evidence-based policy adjustments.

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