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From Chalkboard to Cliks: Digital Media Preferences and Learning Barriers in Distance Organic Chemistry Education

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Abstract: This study investigates students' preferences for digital instructional media and the main learning barriers in the *Organic Chemistry 3* course at Universitas Terbuka (UT), Indonesia's leading open and distance learning institution. Using a descriptive quantitative approach, data were collected from 25 students and alumni through an online questionnaire and analyzed descriptively. The results indicate that interactive simulations (39%) and instructional videos (38%) were the most preferred media, highlighting students' strong preference for dynamic, visualized learning experiences. Major barriers included difficulty in visualizing reaction mechanisms (68%) and insufficient prerequisite mastery (52%), revealing cognitive and structural challenges in learning complex organic chemistry concepts remotely. The analysis further showed a gap between high pedagogical needs (70–85%) and moderate contextual barriers (45–55%), reflecting students' prioritization of instructional quality despite infrastructural limitations. The study concludes that effective distance chemistry instruction must combine strong pedagogical design, technological accessibility, and continuous learner support to foster deep conceptual understanding. Recommendations include integrating step-by-step guided videos, interactive simulations, adaptive scaffolding, and accessible media formats aligned with students' needs and learning contexts.

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INTRODUCTION

In recent years, education systems worldwide have experienced a profound reconfiguration because of swift developments in information and communication technology (ICT) (Misirli & Ergulec, 2021; Zhao & Watterston, 2021). The conventional instructional approach—marked by face-to-face engagement, chalkboard presentation, and tangible course materials—has been steadily supplanted by digital learning frameworks. This shift has been propelled by the widespread availability of high-speed internet, the democratization of digital device ownership, and the embracing of online platforms within academic institutions (Ng et al., 2021; Rapanta et al., 2020). As a result, curricula now commonly incorporate technology-enhanced instructional resources such as Learning Management Systems (LMS), interactive digital modules, video-based lectures, and e-textbooks. These platforms do more than transmit knowledge; they empower learners to engage in adaptive, self-directed, and individualized educational journeys that reflect the complex diversity of today's student populations.

This technological evolution is particularly consequential in university-level disciplines that demand sophisticated abstraction and visualization, notably in the field of chemistry. Organic Chemistry, a foundational pillar within the chemical sciences, imposes intellectual challenges that stem from its emphasis on molecular architecture, functional group dynamics, and intricate reaction pathways (Crucho et al., 2020; Deng & Flynn, 2021). The Organic Chemistry 3 curriculum, in particular, delves into advanced subject matters such as nucleophilic substitution, elimination-addition sequences, and stereochemical analysis—that necessitates a high degree of conceptual agility. For many students, especially those new to organic frameworks, these topics remain elusive and disconnected from everyday experience. Deep understanding relies on constructing and manipulating mental models of molecular interactions, a process that is significantly facilitated by the strategic use of educational technology and interactive media.

The use of instructional media is pivotal in demystifying the complexities of organic chemistry. Visual aids—including dynamic molecular animations, digital simulations of reaction mechanisms, and interactive problem-solving environments—contribute to the cultivation of precise mental images, thereby enhancing conceptual clarity (Dunnagan et al., 2020; Klosterman et al., 2025). These technological tools serve as a conduit between abstract theory and cognitive visualization, equipping students to comprehend reaction mechanisms, energy landscapes, and stereoelectronic phenomena more effectively. Recent pedagogical studies underscore the value of multimodal approaches, wherein the synergy of visual, auditory, and interactive elements fosters deeper learning and superior retention (Mayer, 2021; Sweller et al., 2019). Accordingly, embedding technology-rich media into the curriculum is not simply supplementary, but essential for enabling substantive understanding in conceptually demanding subjects.

Universitas Terbuka (UT), recognized as Indonesia's foremost institution for open and distance learning (ODL), presents a unique environment for the integration of digital instructional media (Padmo et al., 2019; Zuhairi et al., 2020). Distinct from traditional universities with scheduled in-person classes, UT operates entirely through remote, technology-mediated delivery, thus transcending geographic boundaries and granting broad access to higher education. This educational model is intentionally structured to serve a heterogeneous student body—ranging from school leavers to experienced professionals and retirees—each bringing varied academic backgrounds and preparedness for advanced scientific study. These individual differences influence how students interact with instructional content, assimilate knowledge, and formulate learning strategies, underscoring the importance of responsive and adaptive digital resources.

A defining aspect of the UT student profile is the predominance of non-traditional learners who must balance academic commitments with employment, family, and other personal or professional activities. Many are engaged in full-time work, handle domestic responsibilities, or participate in community and business endeavors (Handayani et al., 2022; Kara et al., 2019). While the asynchronous structure of distance education accommodates these varied life circumstances, it also places significant responsibility on students to cultivate self-discipline, maintain internal motivation, and manage their time efficiently. Such requirements become especially pronounced in challenging subjects like Organic Chemistry 3, where deep focus, integration of complex ideas, and repeated practice are vital (Anthonysamy et al., 2020; Jansen et al., 2020). The lack of synchronous, face-to-face support can further complicate progress for students who need ongoing feedback or struggle with independent study routines.

The adoption of digital media for learning within this context brings a dual spectrum of potential and complications. Tools such as instructional videos, immersive 3D molecular models, and interactive assignments can greatly enhance comprehension by rendering abstract ideas into interactive visual experiences. However, unequal access to technology and varying degrees of digital fluency may impede equitable participation (Robinson et al., 2015; van Deursen & van Dijk, 2019). Obstacles such as unreliable or limited internet service, outdated hardware, and disparate levels of digital literacy can all detract from the pedagogical benefits of these resources. For UT's widely distributed and socioeconomically diverse student population, these challenges risk perpetuating or exacerbating disparities in academic achievement, even when robust digital content is available.

Scholarly inquiry into the incorporation of technology in distance education has largely concentrated on general aspects of online learning, with considerably less emphasis on discipline-specific challenges, particularly within scientific fields (Broadbent & Poon, 2015; Rhode et al., 2017). Furthermore, studies exploring how students' preferences for digital instructional media intersect with the unique obstacles encountered in an ODL environment are notably limited. This research void is especially evident in Indonesia's higher education sector, where expansive, open-access systems like UT serve a highly diverse student cohort. Elucidating the interplay between media utilization, learner attributes, and subject-specific hurdles is crucial to developing interventions that foster engagement and drive academic performance.

In light of these considerations, this research endeavors to explore the digital media preferences of current students and alumni enrolled in Organic Chemistry 3 at Universitas Terbuka, while also pinpointing the central obstacles they encounter in mastering the curriculum (J. C. Chen, 2017; Kizilcec et al., 2017). By analyzing trends in media usage, perceived instructional efficacy, and barriers to digital access, the study aims to produce practical insights to guide the development of pedagogically robust, technologically accessible, and context-specific teaching materials. The anticipated outcomes are poised to inform improvements in organic chemistry pedagogy at UT and contribute to broader discussions on technology-driven learning in open and distance education, especially within STEM disciplines. Ultimately, the study aspires to support the design of flexible, equitable, and sustainable digital learning ecosystems that effectively serve the evolving needs of a diverse student body.

METHOD

Research Design

This research utilized a descriptive quantitative methodology to systematically examine the preferences for digital learning media and the obstacles experienced by both students and alumni of Universitas Terbuka (UT) in the Organic Chemistry 3 course. The selection of this method aimed to yield a comprehensive profile of participant demographics, patterns of media usage, and the specific challenges encountered in a distance learning environment.

Participants

Participants comprised current students and alumni from the Chemistry Education program at Universitas Terbuka who had previously enrolled in the Organic Chemistry 3 course. Recruitment was conducted on a voluntary basis by disseminating an online questionnaire using Google Forms. In total, 25 individuals submitted complete and valid responses. The demographic characteristics of the participants are presented in Table 1. The sample comprised 16 females (64%) and 9 males (36%). The participants' ages varied widely, ranging from under 25 years old to over 46 years old, with the largest group being those aged 26–30 years (32%).

Table 1. Demographic Characteristics of Participants

Characteristic	Category	Percentage (%)
Gender	Female	64
	Male	36
Age	< 25 years	24
	26–30 years	32
	31–35 years	12
	36–40 years	16
	41–45 years	12
	> 46 years	4.0
Status	Current student	60
	Alumni	40

Instrument

Data collection was facilitated through an online questionnaire specifically developed to obtain the following information:

1. Demographic characteristics (gender, age, and previous educational background).
2. Preferences for digital learning media used in studying Organic Chemistry
3. Learning barriers encountered when using digital media include both technical and non-technical issues.

The questionnaire included multiple-choice questions, Likert-scale items, and open-ended prompts to capture supplementary qualitative insights.

Table 2. Mapping of Questionnaire Items Q2–Q18

Code	Item (English)	Construct
Q2	How often do you seek supplementary materials beyond lectures to understand Organic Chemistry 3?	Self-directed learning habit
Q3	How complex is the language used in the Organic Chemistry 3 materials, in your view?	Language complexity
Q4	How important are concrete examples for understanding Organic Chemistry 3 content?	Example-based support
Q5	How strong is your need for interactive simulations to support understanding of Organic Chemistry 3?	Media need -Simulation
Q6	How helpful are animations or diagrams for understanding nucleophilic substitution content?	Media usefulness - Visual (Animation/ Diagram)
Q7	How difficult is it for you to understand the concept of nucleophilic substitution mechanisms?	Conceptual difficulty - Understanding mechanism
Q8	How difficult is it for you to construct a nucleophilic substitution mechanism to predict reaction outcomes?	Procedural difficulty - mechanism
Q9	How important is the availability of step-by-step guidance for solving reaction mechanisms?	Scaffolding - Step-by-step guidance
Q10	How effective are interactive videos in helping you understand nucleophilic substitution mechanisms?	Media usefulness - Interactive video
Q11	How useful are three-dimensional models for understanding nucleophilic substitution mechanisms?	Media usefulness -3D model
Q12	How helpful are analogies in simplifying nucleophilic substitution concepts for you?	Media usefulness - Analogy
Q13	How difficult is it for you to manage independent study time in a distance-learning system?	Contextual barrier - Time management
Q14	To what extent is internet connectivity a barrier for you when following online learning?	Contextual barrier - Internet connectivity
Q15	How important is the availability of learning media across devices for you?	Access - Cross-device availability
Q16	Select your preferred learning media (multiple responses allowed).	Preference - Media (multi-response)
Q17	How important are interactive elements in learning media for you?	Media design-Interactivity
Q18	How often have you used digital learning media previously?	Prior exposure - Digital media

Data Collection Procedure

Data collection was conducted over a two-week interval in January 2025. The questionnaire was disseminated through various social media channels and WhatsApp groups dedicated to UT students and alumni. Participation was entirely voluntary, and all respondents received information about the study's objectives prior to completing the instrument.

Data Analysis

Quantitative data were analyzed employing descriptive statistical techniques to obtain frequency distributions and percentages. Qualitative responses from open-ended items were examined through content analysis to identify key themes associated with learning barriers.

RESULT AND DISCUSSION

The advancement of digital media in education has profoundly transformed how students learn and comprehend scientific concepts, particularly within Open and Distance Learning (ODL) systems. At Universitas Terbuka (UT), where all courses are delivered entirely online, instructional media do not merely supplement the teaching process—they serve as the primary bridge between lecturers and students. In this context, the choice and design of media are crucial for helping students construct mental models—internal representations of molecular structures and reaction mechanisms that are invisible to the naked eye. This is especially important in the Organic Chemistry 3 course, which requires a high degree of abstract thinking and mechanistic reasoning. This study aimed to identify students' preferences for digital instructional media and the main barriers they face in the learning process. Understanding these two aspects enables the development of more effective, evidence-based instructional designs that align with students' actual learning needs. The findings reveal that students' learning experiences are shaped by complex interactions among cognitive abilities, technological accessibility, and diverse socio-economic contexts.

Digital Media Preferences

Survey results (Figure 1) revealed that interactive simulations were the preferred learning media (39%), followed closely by instructional videos (38%). Interactive e-books received moderate support (20%), while 3D molecular models were the least favored (3%). This distribution indicates that students prefer dynamic, process-oriented media that visualize chemical transformations step by step, rather than static materials such as text or still images. This preference aligns strongly with (Mayer's Cognitive Theory of Multimedia Learning (2020), which posits that learning becomes more effective when information is presented through both visual and verbal channels simultaneously. This dual coding mechanism reduces extraneous cognitive load and promotes better integration of new knowledge with existing cognitive schemas (Mayer, 2020). In organic chemistry—where reactions involve complex sequences of electron movements, bond formation and breaking, and stereochemical changes—static diagrams often fail to adequately represent these dynamic molecular processes. Research by Silva & Sasseron, (2025) demonstrated that students who relied solely on static representations struggled to develop accurate mental models of reaction pathways, frequently misinterpreting the temporal sequence of mechanistic steps. Thus, animations and simulations play an essential role in bridging the gap between abstract theoretical concepts and their visual representations, allowing students to observe molecular transformations as they unfold over time.

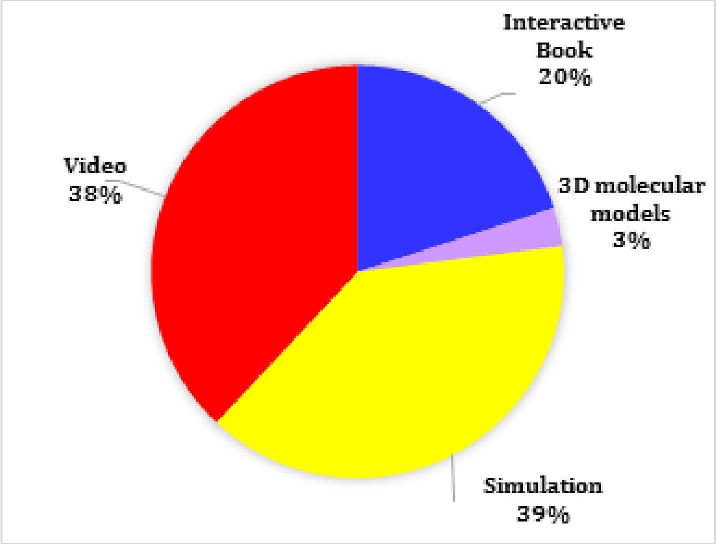

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Figure 1. Prederred Instructional Media

The dominance of interactive simulations (39%) can be explained through embodied cognition theory, which posits that learning deepens when learners actively manipulate representations and receive immediate feedback on their actions (Barsalou, 2020). This theoretical framework suggests that physical or virtual manipulation of molecular structures allows students to internalize spatial relationships and mechanistic sequences more effectively than passive observation. This finding aligns with recent empirical evidence in chemistry education: Dood & Watts, (2022) demonstrated that students using molecular simulations achieved 23% higher scores in mechanistic reasoning tasks compared to those learning from static diagrams alone. Similarly, Rodríguez-Blas et al., (2021) found that interactive manipulation of molecular models reduced cognitive load by allowing learners to "experience" rather than merely observe molecular transformations, thereby facilitating the construction of more robust mental models.

However, our finding of 39% preference for simulations is notably lower than the 67% reported by Chen et al., (2024) in a similar ODL chemistry context in Taiwan. This discrepancy may be attributed to several contextual factors specific to the Indonesian ODL environment. First, internet infrastructure variability across Indonesia's archipelagic geography may limit students' ability to reliably access bandwidth-intensive simulation tools (Padmo et al., 2019). Second, prior exposure to digital learning technologies varies considerably among UT's diverse student population, which includes both recent school graduates and mature learners returning to education after extended periods in the workforce (Zuhairi et al., 2020). Students with limited prior experience with interactive digital tools may gravitate toward more familiar formats such as instructional videos, which require less digital literacy and technical troubleshooting.

The strong preference for instructional videos (38%) merits deeper examination within the context of distance learning constraints. Instructional videos offer several distinct advantages for ODL learners: they can be paused, replayed, and reviewed at the learner's own pace; they accommodate diverse learning schedules and time constraints; and they require less real-time bandwidth than interactive simulations (Rapanta et al., 2020). For UT students who often balance academic pursuits with full-time employment and family responsibilities, the flexibility inherent in video-based instruction represents a critical affordance (Handayani et al., 2022). Furthermore, well-designed instructional videos can incorporate multiple representational levels—macroscopic phenomena, submicroscopic molecular processes, and symbolic notation—thereby supporting students' ability to translate between different representational modes, a key competency in chemistry learning (Crucho et al., 2020).

Conversely, the lower preference for 3D molecular models (3%) warrants critical interpretation beyond face-value acceptance. This finding appears to contradict substantial evidence for 3D visualization's pedagogical value in understanding stereochemistry and spatial molecular arrangements (Bullock & Huwer, 2024). However, recent implementation studies reveal that the effectiveness of 3D models depends heavily on instructional integration and technological accessibility. Klosterman et al., (2025) found that 3D molecular models were most effective when integrated within a guided instructional framework that explicitly directed students' attention to relevant spatial features, rather than presented as standalone exploratory tools. Without such scaffolding, students may struggle to extract relevant information from complex three-dimensional representations, particularly when viewing them on two-dimensional screens without haptic feedback. Additionally, rendering and manipulating 3D models often requires robust graphics processing capabilities and stable internet connections, which may not be uniformly available across UT's geographically dispersed student population.

Learning Barriers

The study identified four major barriers faced by students in mastering Organic Chemistry 3 content (Table 1). The most prominent barrier was difficulty visualizing reaction mechanisms (68%), followed by insufficient mastery of prerequisite knowledge (52%), difficulty understanding abstract material (40%), and limited access to comprehensive learning resources (36%). This hierarchy of barriers reveals important insights into the cognitive and structural challenges inherent in distance chemistry education.

The finding that 68% of students struggle with visualization of reaction mechanisms is consistent with extensive literature documenting visualization as a central challenge in organic chemistry education. Deng & Flynn, (2021) reported that students frequently struggle to construct accurate mental representations of electron movement, bond reorganization, and intermediate species formation—all essential components of mechanistic reasoning. Our findings aligns closely with their observation that many students approach mechanism problems algorithmically, memorizing patterns rather than developing conceptual understanding of electronic factors driving reactivity. This visualization deficit has profound implications for learning outcomes: Torres et al., (2024) demonstrated that students who failed to develop robust visualization skills in foundational courses showed persistent difficulties in advanced topics, with visualization ability serving as a significant predictor of performance in upper-level chemistry courses.

Table 1. Barriers to Learning

No	Barrier	%
1	Difficulty visualizing reaction mechanisms	68%
2	Lack of mastery of prerequisite courses	52%
3	Difficulty understanding the material	40%
4	Limited access to comprehensive resources	36%

The theoretical basis for understanding visualization difficulties lies in the inherent characteristics of molecular phenomena. Chemical reactions occur at scales and speeds beyond direct human perception, requiring students to construct and manipulate abstract mental models of invisible entities (Bongers et al., 2019). This abstraction challenge is compounded in distance learning environments where students lack face-to-face interactions with instructors who might use gestures, physical models, or real-time drawing to scaffold visualization (Crucho et al., 2020). Furthermore, organic chemistry employs a specialized symbolic system—curved arrow notation, Lewis structures, and stereochemical descriptors—that students must master simultaneously while developing their conceptual understanding, creating substantial cognitive demands (Dood & Watts, 2022).

The second most prevalent barrier—insufficient mastery of prerequisite knowledge (52%)—highlights a structural challenge in cumulative scientific disciplines. Organic chemistry builds hierarchically upon foundations established in general chemistry, including concepts of electronegativity, molecular orbital theory, acid-base chemistry, and thermodynamics (Torres et al., 2024). When students enter Organic Chemistry 3 with gaps in this foundational knowledge, they face compounding difficulties as new concepts require integration with inadequately developed prior understanding. This challenge is particularly acute in ODL environments where student populations are highly heterogeneous in educational background and time elapsed since completing prerequisite courses (Chen, 2017).

Lansangan, (2021) demonstrated that targeted diagnostic assessment followed by just-in-time remediation significantly improved learning outcomes for students with prerequisite knowledge gaps. However, implementing such interventions in large-scale ODL environments presents logistical challenges, requiring automated diagnostic systems and adaptive learning pathways that respond to individual student needs. The 52% prevalence of prerequisite knowledge gaps identified in our study suggests that such interventions should be considered essential components of course design rather than optional supplements.

The barrier of difficulty understanding abstract material (40%) overlaps substantially with visualization challenges but encompasses broader issues of conceptual accessibility. Organic chemistry concepts often involve multiple levels of abstraction: understanding that molecular properties emerge from electronic structure, that reactivity patterns reflect thermodynamic and kinetic factors, and that symbolic representations correspond to three-dimensional molecular reality (Silva & Sasseron, 2025). For distance learners without access to synchronous clarification from instructors or peers, these abstract concepts can remain opaque despite repeated review of course materials (Jansen et al., 2020).

Limited access to comprehensive learning resources (36%) represents the most tangible and potentially addressable barrier identified in this study. Unlike the cognitive challenges of visualization and abstraction, resource limitations stem primarily from infrastructure and design choices that can be modified through institutional action. However, the relationship between resource access and learning outcomes is mediated by how effectively students can locate, evaluate, and integrate available resources into their learning processes (Robinson et al., 2015). Van Deursen & van Dijk, (2019) distinguished between "first-level digital divide" (access to technology) and "second-level digital divide" (skills to use technology effectively), noting that both dimensions influence educational equity in online learning environments.

Instructional Priorities

Analysis of questionnaire items Q2–Q18 (Figure 2) revealed that students highly prioritized step-by-step guidance, interactive visualization, and cross-device accessibility, with average ratings between 4.0 and 4.5 on a 5-point Likert scale. This pattern underscores students' preference for structured, visually enriched, and flexible learning experiences that accommodate their diverse circumstances and learning needs. The high priority assigned to step-by-step guidance aligns with Cognitive Load Theory, which emphasizes that breaking down complex procedures into manageable sequential steps helps learners manage intrinsic cognitive load—the inherent difficulty of the material itself (Sweller, 2020). In the context of organic chemistry mechanisms, step-by-step guidance serves multiple functions: it reduces working memory demands by chunking information into smaller units; it makes implicit expert reasoning explicit and visible to novices; and it provides clear organizational structure for knowledge that might otherwise appear overwhelming in complexity (Castro-Alonso et al., 2021).

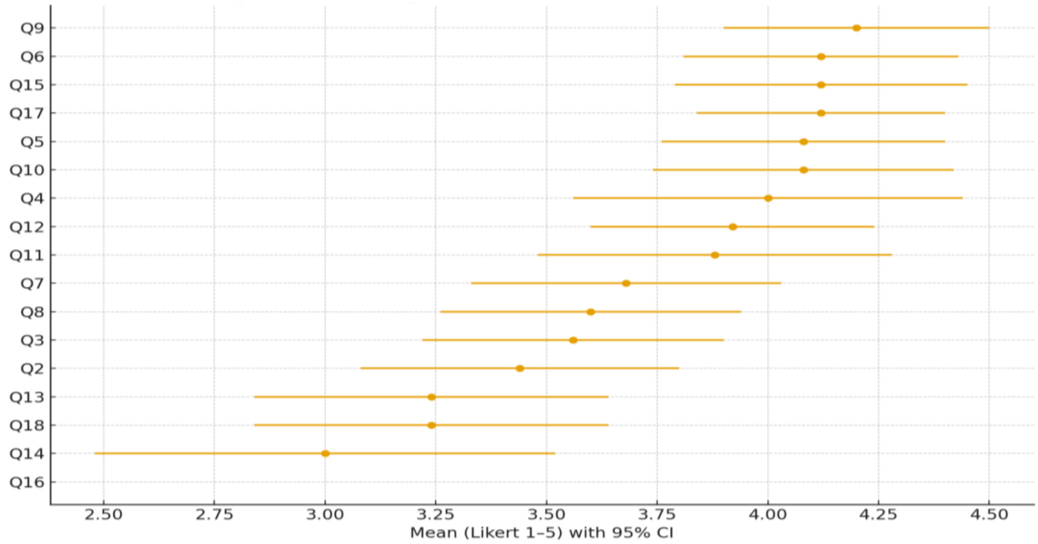

Figure 2. Ranking Plot of Questionnaire Items (Q2–Q18)

The theoretical basis for step-by-step instruction has been refined by recent research distinguishing between procedural and conceptual scaffolding. Castro-Alonso et al., (2021) conducted a comparative study showing that "procedural scaffolding" (breaking tasks into steps showing what to do) combined with "conceptual scaffolding" (explaining why each step occurs) produced the strongest learning effects (Cohen's d = 0.83), significantly outperforming procedural-only (d = 0.34) or conceptual-only (d = 0.41) approaches. This suggests that UT's implementation of step-by-step guidance should integrate both procedural demonstration and conceptual explanation, showing not just how mechanisms proceed but why each step occurs based on electronic principles, steric factors, and thermodynamic considerations. For example, in teaching nucleophilic substitution mechanisms, effective instruction should not merely show the sequence of bond-breaking and bond-forming steps but should explicitly explain how each step is driven by nucleophile-electrophile interactions, how electron density redistribution occurs, and why particular intermediates form under specific conditions.

The high value students placed on interactive visualization (mean rating 4.3) reinforces the findings from the media preference section while providing additional nuance. Students recognize that interactivity transforms visualization from passive observation to active cognitive engagement (Chi & Wylie, 2014). The ICAP framework—distinguishing Interactive, Constructive, Active, and Passive modes of engagement—positions interactive manipulation as producing deeper learning than constructive generation, which in turn exceeds active observation and passive reception (Chi & Wylie, 2014; Irwanto, 2017). In the context of organic chemistry learning, interactive visualization allows students to test hypotheses about molecular behavior, receive immediate feedback on their predictions, and iteratively refine their mental models—processes that are difficult to achieve with static or linear instructional materials (Dunnagan et al., 2020).

Cross-device accessibility received high priority ratings (mean 4.4), reflecting the diverse technological contexts in which UT students engage with course materials. Students may access content from desktop computers at work, smartphones during commutes, or tablets at home, necessitating responsive design that maintains functionality across platforms and screen sizes (Padmo et al., 2019; Richardson Mbukusa, 2018). This requirement extends beyond mere technical compatibility to include pedagogical considerations: instructional activities designed for large screens with mouse input may not translate effectively to small touchscreens, requiring adaptive activity design that preserves learning objectives while accommodating interface constraints.

Moderate ratings for 3D models and analogies (3.5–4.0) suggest that students view these tools as useful but supplementary rather than essential. This finding demonstrates metacognitive sophistication: students recognize that 3D models are particularly effective for spatial topics such as stereochemistry and conformational analysis, while analogies aid understanding primarily when sufficient prior knowledge exists to support analogical mapping (Mayer, 2020). This discrimination among learning tools challenges deficit narratives about ODL student preparedness and suggests that students exercise reflective judgment in identifying which resources best serve their learning needs in specific contexts.
Contextual factors—including time management (mean 3.3), internet connectivity (mean 3.2), and digital literacy (mean 3.4)—received slightly lower ratings than pedagogical factors, indicating that while these issues persist, students view conceptual understanding and instructional quality as more pressing concerns. This finding has important implications for resource allocation and design priorities. It suggests that investments in pedagogical improvement—developing clearer explanations, better-scaffolded activities, and more effective visualizations—may yield greater learning benefits than investments purely in technological infrastructure, though both remain important (Henderikx et al., 2018). However, the moderate ratings for contextual barriers should not be interpreted as indicating these factors are unimportant. Rather, they reflect students' recognition that even with perfect internet connectivity and unlimited time, poor instructional design would still impede learning. Conversely, excellent instruction delivered through inaccessible or inefficient platforms will fail to reach learners effectively (Stone & O'Shea, 2019). The implication is that effective ODL chemistry education requires simultaneous attention to pedagogical soundness and practical accessibility, rather than prioritizing one dimension at the expense of the other.

Pedagogical Needs and Contextual Barriers

Figure 3 illustrates the comparison between pedagogical needs and contextual barriers, revealing an asymmetric pattern wherein pedagogical needs (step-by-step guidance 85%, scaffolding 78%, interactive videos 76%, animations 72%) substantially exceed contextual barriers (time management 52%, internet connectivity 48%, device accessibility 45%). This asymmetry contradicts common assumptions about ODL student priorities, which often emphasize logistical and technological obstacles over pedagogical quality concerns. The pattern suggests that UT students, despite facing real constraints in time availability, internet access, and technological resources, nonetheless prioritize instructional effectiveness and learning support as their primary needs.

This finding aligns with research by Anthonysamy et al., (2020) demonstrating that self-regulated learning strategies—which depend heavily on clear instructional structure and explicit guidance—predict academic success in blended learning environments more strongly than technological factors alone. Students who can effectively regulate their learning can often compensate for technological limitations through strategic planning but cannot compensate for poor instruction through increased effort (Kizilcec et al., 2017). The implication is that course design investments should prioritize pedagogical robustness while simultaneously addressing accessibility barriers, rather than treating these as competing priorities requiring trade-offs.

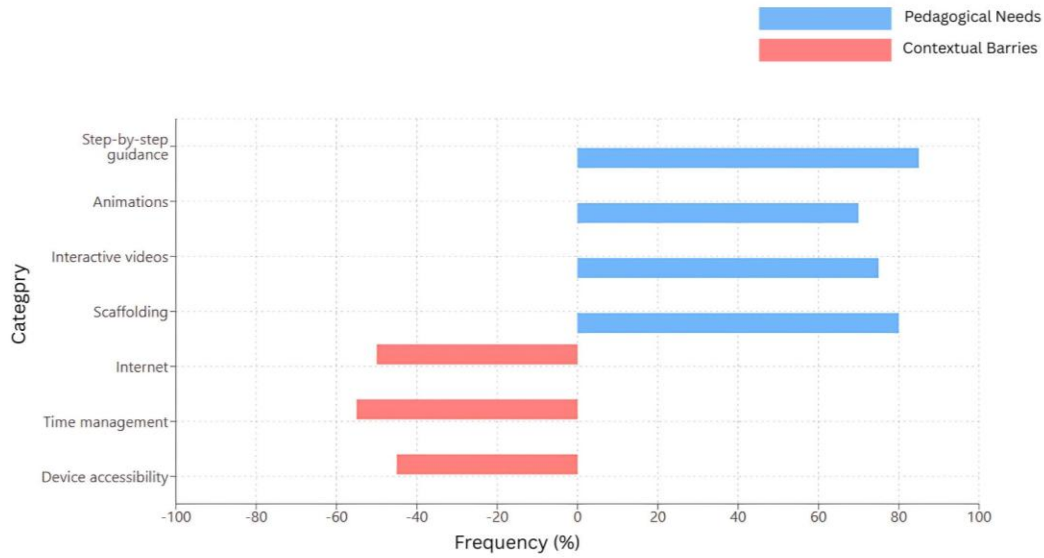

Figure 3. Comparison Plot: Pedagogical Needs vs. Contextual Barriers

The relatively lower priority assigned to time management barriers (52%) compared to pedagogical needs (70-85%) warrants careful interpretation. This pattern does not suggest that time constraints are unimportant; rather, it indicates that students believe even with adequate time, ineffective instruction would prevent learning, whereas effective instruction can enable learning even within constrained timeframes. This perspective reflects the reality of adult learners who have developed strategies for time management through professional and personal experience, but who lack strategies for conceptual understanding in unfamiliar domains like advanced organic chemistry (Kara et al., 2019). Internet connectivity barriers (48%) represent a persistent challenge in Indonesia's geographically dispersed and economically diverse context. However, the moderate priority assigned to this factor suggests that students have adapted to connectivity limitations through strategies such as downloading materials during periods of good connectivity, accessing content during off-peak hours when network congestion is reduced, or using mobile data when home internet is unavailable (Padmo et al., 2019). These adaptive strategies impose additional cognitive and logistical burdens on learners, and course design can mitigate these burdens by providing content in multiple formats—high-resolution versions for users with reliable broadband, compressed versions for mobile or limited connectivity, and text-based alternatives for offline access.

Integration of Social Learning

The high priority students assigned to structured guidance and scaffolding (85% and 78% respectively) suggests an underlying need for social learning opportunities that may not be fully satisfied by individual interaction with digital materials alone. Social constructivist learning theory posits that knowledge construction occurs through social interaction, collaborative problem-solving, and negotiation of meaning within learning communities (Chi & Wylie, 2014). While digital materials can provide explicit guidance, they cannot fully replicate the dynamic feedback, multiple perspectives, and motivational support available through peer and instructor interaction. The ICAP framework positions Interactive engagement—defined as dialogic interaction with peers or instructors—as producing the deepest learning outcomes (Chi & Wylie, 2014). Students who explain mechanisms to peers must articulate implicit reasoning, confront contradictions in their understanding, and refine mental models through the process of making their thinking visible and responding to questions or challenges (Bongers et al., 2019; McNeil, 2015). This aligns with our finding that 85% of students seek step-by-step guidance: they recognize that observing expert reasoning is valuable, but generating and defending their own explanations produces deeper conceptual transformation.

Implementation of social learning in ODL chemistry contexts could involve several design strategies. Structured peer review of mechanism proposals, where students critique each other's electronpushing diagrams using rubrics focusing on arrow notation accuracy, resonance structure validity, and stereochemical consistency, would promote both explanation generation and critical evaluation—both high-value cognitive activities (Blackley et al., 2018; Deng & Flynn, 2021). Asynchronous discussion forums organized around specific mechanistic challenges, where students must first propose their own solutions before viewing others' approaches, would encourage commitment to initial reasoning while still providing access to alternative perspectives. Synchronous virtual problem-solving sessions, even if infrequent, would offer opportunities for real-time collaborative reasoning that asynchronous tools cannot fully replicate(Martin & Bolliger, 2018; Rapanta et al., 2020).

Synthesizing the findings on media preferences, learning barriers, and instructional priorities yields targeted recommendations for Organic Chemistry 3 course enhancement at Universitas Terbuka. Course designers should prioritize interactive video modules of 6–8 minutes, incorporating embedded formative assessments and color-coded animations that signal electron movements while pausing at critical junctures to prompt predictive reasoning (Mayer, 2020; Sweller et al., 2019). Rather than separate remediation modules, diagnostic pre-assessments should trigger just-in-time contextualized review of prerequisite concepts—such as acid-base chemistry and electronegativity—embedded directly where relevant in mechanism instruction (Lansangan, 2021). Multi-modal accessibility must accommodate Indonesia's diverse connectivity contexts through parallel delivery formats: high-resolution simulations for broadband users, compressed videos for mobile learners, static image sequences for low-bandwidth contexts, and text-based alternatives for offline access (Irwanto et al., 2023; Padmo et al., 2020; Robinson et al., 2015). Analytics-driven temporal scaffolding should adaptively release content based on prerequisite completion patterns while offering micro-credentials recognizing incremental mastery, accommodating working adults' complex schedules (Anthonysamy et al., 2020). Finally, explicit visualization training through scaffolded representational translation exercises—moving systematically between molecular formulas, Lewis structures, 3D models, and mechanisms—develops both procedural fluency and conceptual understanding essential for mechanistic reasoning (Dood & Watts, 2022).

This study advances theoretical understanding of technology-mediated chemistry learning by demonstrating that Cognitive Load Theory and Multimedia Learning Theory retain explanatory power in ODL contexts while requiring adaptation for distance-specific cognitive demands including navigation complexity and absence of synchronous support (Sweller et al., 2019). Students' prioritization of pedagogical quality over logistical convenience reveals that germane cognitive load directed toward schema construction remains the primary learning driver even when extraneous loads increase. The documented asymmetry between pedagogical needs (70-85%) and contextual barriers (45-55%) demonstrates that ODL learners exercise sophisticated metacognitive judgment, accurately identifying instructional insufficiencies rather than attributing difficulties to external factors (Zhang et al., 2017). This challenges deficit models and redirects institutional focus toward instructional quality enhancement. The preference hierarchy—interactive simulations > instructional videos > interactive e-books > 3D models—illuminates adaptive resource allocation under cognitive and technological constraints, suggesting that effective ODL design must provide graduated media options rather than assuming universal "best practices" apply across diverse learner contexts.

CONCLUSION

Organic Chemistry 3's success in distance education, as the findings indicate, transcends mere technological provision. What proves essential is a triad of elements: pedagogically sound instruction, digitally accessible tools, and persistent support mechanisms, the latter being particularly critical in guiding learners through remote education challenges. At Universitas Terbuka, students demonstrate notable awareness of their own learning dynamics. Interactive and visual media, they recognize, serve as effective solutions to visualization obstacles, while prerequisite knowledge deficiencies require contextual scaffolding integrated into course structure. Time pressures and connectivity barriers remain, yet learners repeatedly emphasize that superior teaching quality and structured mentorship matter more than technical specifications alone. The practical implication points toward learning environment design that achieves both pedagogical soundness and technological inclusiveness. Instructional design in resource-constrained ODL environments should follow dual optimization—simultaneously maximizing learning efficacy and access equity. Through Universal Design for Learning (UDL) adoption, institutions can ensure flexible, multi-format delivery that serves varied student populations equitably. When Universitas Terbuka aligns its pedagogical strategies with its resource capacity and student demographics, it constructs a durable learning infrastructure. This infrastructure enables every student, without regard to prior background, to develop substantial comprehension and accomplish meaningful outcomes in organic chemistry.

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REFERENCES

Anthonysamy, L., Koo, A. C., & Hew, S. H. (2020). Self-regulated learning strategies and non-academic outcomes in higher education blended learning environments: A one decade review. *Education and Information Technologies*, *25*, 3677-3704. https://doi.org/https://doi.org/10.1007/s10639-020-10134-2

Barsalou, L. W. (2020). Challenges and opportunities for grounding cognition. *Journal of Cognition, 3*(1), Article 31. https://doi.org/https://doi.org/10.5334/joc.116

Blackley, S., Rahmawati, Y., Fitriani, E., Sheffield, R., & Koul, R. (2018). Using a makerspace approach to engage Indonesian primary students with STEM. *Issues in Educational Research*, *28*(1), 18–42.

Bongers, A., Northoff, G., & Flynn, A. B. (2019). Working with mental models to learn and visualize a new reaction mechanism. *Chemistry Education Research and Practice*, *20*(3), 554–569. https://doi.org/10.1039/c9rp00060g

Broadbent, J., & Poon, W. L. (2015). Self-regulated learning strategies & academic achievement in online higher education learning environments: A systematic review. *The Internet and Higher Education*, *27*, 1–13. https://doi.org/https://doi.org/10.1016/j.iheduc.2015.04.007

Bullock, M., & Huwer, J. (2024). Using AR to Enhance the Learning of Chirality. *Education Sciences*, *14*(11). https://doi.org/10.3390/educsci14111214

Castro-Alonso, J. C., Wong, R. M., Adesope, O. O., & Paas, F. (2021). Effectiveness of Multimedia Pedagogical Agents Predicted by Diverse Theories: a Meta-Analysis. *Educational Psychology Review*, *33*(3), 989–1015. https://doi.org/10.1007/s10648-020-09587-1

Chen, J. C. (2017). Nontraditional adult learners: The neglected diversity in postsecondary education. *SAGE Open*, *7*(1). https://doi.org/10.1177/2158244017697161

Chen, K. F., Hwang, G. J., & Chen, M. R. A. (2024). Effects of a concept mapping-guided virtual laboratory learning approach on students' science process skills and behavioral patterns. *Educational Technology Research and Development*, *72*(3), 1623–1651. https://doi.org/10.1007/s11423-024-10348-y

Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, *49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Crucho, C. I. C., Avó, J., Diniz, A. M., & Gomes, M. J. S. (2020). Challenges in teaching organic chemistry remotely. *Journal of Chemical Education*, *97*(9), 3211–3216. https://doi.org/https://doi.org/10.1021/acs.jchemed.0c00693

Deng, J. M., & Flynn, A. B. (2021). Reasoning, granularity, and comparisons in students' arguments on two organic chemistry items. *Chemistry Education Research and Practice, 22*(3), 749-771. https://doi.org/https://doi.org/10.1039/D0RP00320D

Dood, A. J., & Watts, F. M. (2022). Mechanistic Reasoning in Organic Chemistry: A Scoping Review of How Students Describe and Explain Mechanisms in the Chemistry Education Research Literature. *Journal of Chemical Education*, *99*(8), 2864–2876. https://doi.org/10.1021/acs.jchemed.2c00313

Dunnagan, C. L., Dannenberg, D. A., Cuales, M. P., Earnest, A. D., Gurnsey, R. M., & Gallardo-Williams, M. T. (2020). Production and Evaluation of a Realistic Immersive Virtual Reality Organic Chemistry Laboratory Experience: Infrared Spectroscopy. *Journal of Chemical Education*, *97*(1), 258–262. https://doi.org/10.1021/acs.jchemed.9b00705

Handayani, T., Maksum, A., & Suhendri, H. (2022). The students' learning difficulties at the Open University webinar tutorial. *JPI (Jurnal Pendidikan Indonesia)*, *11*(3), 465-475. https://doi.org/https://doi.org/10.23887/jpi-undiksha.v11i3.51585

Henderikx, M., Kreijns, K., & Kalz, M. (2018). A Classification of Barriers that Influence Intention Achievement in MOOCs. In *Lifelong Technology-Enhanced Learning* (Vol. 11082). Springer, Cham. https://doi.org/https://doi.org/10.1007/978-3-319-98572-5_1

Irwanto, I. (2017). Using Virtual Labs To Enhance Students' Thinking Abilities, Skills, and Scientific Attitudes. *International Conference on Educational Research and Innovation*, *ICERI*, 494–499. https://doi.org/10.31227/osf.io/vqnkz

Irwanto, I., Afrizal, A., Lukman, I. R., Agung, D., & Wijayako, R. S. (2023). Go-Chemist! App and Its Impact on Students' Attitudes Toward Chemistry. *TEM Journal*, *12*(3), 1638–1644. https://doi.org/10.18421/TEM123-45

Jansen, R. S., van Leeuwen, A., Janssen, J., Kester, L., & Kalz, M. (2020). Validation of the self-regulated online learning questionnaire. *Journal of Computing in Higher Education*, *32*(1), 44-68. https://doi.org/https://doi.org/10.1007/s12528-019-09225-y

Kara, M., Erdoğdu, F., Kokoç, M., & Cagiltay, K. (2019). Challenges Faced by Adult Learners in Online Distance Education: A Literature Review. *Open Praxis*, *11*(1), 5. https://doi.org/10.5944/openpraxis.11.1.929

Kizilcec, R. F., Pérez-Sanagustín, M., & Maldonado, J. J. (2017). Self-regulated learning strategies predict learner behavior and goal attainment in massive open online courses. *Computers & Education*, *104*, 18-33. https://doi.org/https://doi.org/10.1016/j.compedu.2016.10.001

Klosterman, J. K., Martin, H., Rocio, A., & Nolan, N. (2025). Accessible molecular models: A modular 3D-printed space-filling atomic model set and active learning modules for introductory organic chemistry. *Journal of Chemical Education*, *102*, 583-592. https://doi.org/https://doi.org/10.1021/acs.jchemed.5c00518

Lansangan, R. V. (2021). Articulating the Barriers in the Online Learning Engagement in Chemistry of Junior High School Students: A Photovoice Study. *Electronic Journal for Research in Science & Mathematics Education*, *26*(2), 56–76.

Martin, F., & Bolliger, D. U. (2018). Engagement matters: Student perceptions on the importance of engagement strategies in the online learning environment. *Online Learning Journal*, *22*(1), 205–222. https://doi.org/10.24059/olj.v22i1.1092

Mayer, R. E. (2020). *Multimedia learning for the third decade: A cognitive theory of multimedia learning. Cambridge Handbook of Multimedia Learning (3rd ed.)*. Cambridge University Press. https://doi.org/https://doi.org/10.1017/9781108894333.002

Mayer, R. E. (2021). *Multimedia learning (3rd ed.)*. Cambridge University Press.

McNeil, S. (2015). Visualizing mental models: understanding cognitive change to support teaching and learning of multimedia design and development. *Educational Technology Research and Development*, *63*(1), 73–96. https://doi.org/10.1007/s11423-014-9354-5

Misirli, O., & Ergulec, F. (2021). Emergency remote teaching during the COVID-19 pandemic: Parents experiences and perspectives. *Education and Information Technologies*, *26*(6), 6699–6718. https://doi.org/10.1007/s10639-021-10520-4

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021). Conceptualizing AI literacy: An exploratory review. *Computers and Education: Artificial Intelligence*, *2*, 100041. https://doi.org/10.1016/j.caeai.2021.100041

Padmo, D., Idrus, O., & Ardiasih, L. S. (2019). The utilization of mobile devices for improving access to online learning for distance Education's Students. *Turkish Online Journal of Distance Education*, *20*(2), 147–161. https://doi.org/10.17718/tojde.557858

Padmo, D., Sri Ardiasih, L., & Idrus, O. (2020). Online Learning During the Covid-19 Pandemic and Its Effect on Future Education in Indonesia. In *The Impact Of COVID19 On The International Education System* (In Ljupka, pp. 71–86). Proud Pen. https://doi.org/10.51432/978-1-8381524-0-6_5

Rapanta, C., Botturi, L., Goodyear, P., Guàrdia, L., & Koole, M. (2020). Online University Teaching During and After the Covid-19 Crisis: Refocusing Teacher Presence and Learning Activity. *Postdigital Science and Education*, *2*(3), 923–945. https://doi.org/10.1007/s42438-020-00155-y

Rhode, J., Richter, S., Gowen, P., Miller, T., & Wills, C. (2017). Understanding faculty use of the learning management system. *Online Learning Journal*, *21*(3), 68–86. https://doi.org/10.24059/olj.v21i3.1217

Richardson Mbukusa, N. (2018). Perceptions of students' on the Use of WhatsApp in Teaching Methods of English as Second Language at the University of Namibia. *Journal of Curriculum and Teaching*, *7*(2). https://doi.org/10.5430/jct.v7n2p112

Robinson, L., Cotten, S. R., Ono, H., Quan-Haase, A., Mesch, G., Chen, W., Schulz, J., Hale, T. M., & Stern, M. J. (2015). Digital inequalities and why they matter. Information. *Communication & Society*, *18*(5), 569-582. https://doi.org/https://doi.org/10.1080/1369118X.2015.1012532

Rodríguez-Blas, T., De Blas, A., Latorre-López, M. J., & Picos-Nebril, S. (2021). "f ind y our P ersonal e lements": An Engaging Approach to Introducing Chemistry to Secondary School Students. *Journal of Chemical Education*, *98*(6), 2012–2016. https://doi.org/10.1021/acs.jchemed.1c00002

Silva, F. C., & Sasseron, L. H. (2025). The Positioning of Visual Representations As Epistemic Objects for the Teaching of Organic Chemistry. *Journal of Chemical Education*, *102*(2), 615–620. https://doi.org/10.1021/acs.jchemed.4c01018

Stone, C., & O'Shea, S. (2019). Older, online and first: Recommendations for retention and success and the National Centre for Student Equity in Higher Education and the National Centre for Student Equity in Higher Education. *Australasian Journal of Educational Technology*, *35*(1), 57–69.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. *Educational Psychology Review*, *31*(2), 261–292. https://doi.org/10.1007/s10648-019-09465-5

Torres, D., Pulminskas, A., & Abrams, B. (2024). Development of the Organic and Biochemistry Readiness Instrument: Assessing Student Preparedness for Organic Chemistry and Biochemistry. *Journal of Chemical Education*, *101*(8), 3352–3361. https://doi.org/10.1021/acs.jchemed.4c00480

van Deursen, A. J. A. M., & van Dijk, J. A. G. M. (2019). The first-level digital divide shifts from inequalities in physical access to inequalities in material access. *New Media and Society*, *21*(2), 354–375. https://doi.org/10.1177/1461444818797082

Zhang, S., Liu, Q., Chen, W., Wang, Q., & Huang, Z. (2017). Interactive networks and social knowledge construction behavioral patterns in primary school teachers' online collaborative learning activities. *Computers & Education*. https://www.sciencedirect.com/science/article/pii/S036013151630197X

Zhao, Y., & Watterston, J. (2021). The changes we need: Education post COVID-19. *Journal of Educational Change*, *22*(1), 3–12. https://doi.org/10.1007/s10833-021-09417-3

Zuhairi, A., Karthikeyan, N., & Priyadarshana, S. T. (2020). Supporting students to succeed in open and distance learning in the Open University of Sri Lanka and Universitas Terbuka Indonesia. *Asian Association of Open Universities Journal*, *15*(1), 13–35. https://doi.org/10.1108/AAOUJ-09-2019-0038