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Accommodating Diverse Learning Styles in Undergraduate Chemistry: A Mixed-Methods Study on Differentiated Interactive Learning Materials

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Abstract: This study investigates chemistry students' perceptions of Interactive Learning Materials (ILMs) developed using a differentiated instruction approach. The research employed a mixed-methods design involving 62 undergraduate students in the Chemistry Education Program, Universitas Negeri Makasar, Indonesia, who completed a perception questionnaire and a validated online learning-style assessment. Descriptive analysis revealed that students' overall perceptions of the ILMs were highly positive across six dimensions: preliminary experience, relevance, conceptual comprehension, differentiation, motivation, and effectiveness. In addition, a Kruskal–Wallis inferential test was conducted on a subset of 46 valid respondents to examine whether perception scores differed significantly across learning-style groups. The results indicated no statistically significant differences among the seven learning-style categories ($H(6, 46) = 4.72$, $p = .58$), suggesting that the ILMs were perceived positively and consistently across all groups. Qualitative responses further supported these findings, highlighting that kinesthetic learners valued interactive features but desired richer hands-on engagement. Overall, the study confirms that ILMs with differentiated pathways can effectively support diverse learners in mastering abstract chemistry concepts, while emphasizing the need for future development to integrate more kinesthetic and exploratory elements.

Keywords: interactive learning materials, differentiated instruction, learning styles, chemistry education, student perceptions.

▪ INTRODUCTION

Chemistry education at the university level is often marked by significant difficulties, stemming from the abstract nature of its core concepts, such as molecular structures and thermodynamic principles. Conventional teaching practices have historically emphasized the transmission of content and mastery of procedures, frequently overlooking the importance of engaging students in deeper learning processes The appropriate use of formative feedback has been shown to enhance both student achievement and learning motivation, shifting the focus from mere content delivery to how learners construct meaning from complex concepts (Aslam, 2021; Cohen & Singh, 2020; Karaman, 2021). The ongoing digital transformation in higher education has also introduced a range of innovative pedagogical resources, such as dynamic visualizations and interactive simulations, that strengthen students' comprehension and increase engagement in chemistry learning (Davenport et al., 2018; Wong et al., 2021). Furthermore, pedagogical practices that emphasize timely and constructive feedback are essential, as they enable instructors to adapt their teaching to diverse student learning trajectories while fostering a more supportive educational environment (Ewim & Opateye, 2021; Hooda et al., 2022). Within this context, the growing emphasis on student-centered learning frameworks raises critical concerns regarding accessibility and the modes of knowledge representation, compelling educators to address not only the content

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of instruction but also the mechanisms that facilitate student learning (Mngomezulu et al., 2024; Wu & Yezierski, 2023).

Well-designed interactive learning materials (ILMs) significantly increase student engagement. These materials also support understanding in chemistry learning by integrating multimodal representations, such as animations and simulations. These materials can bridge the gap between macroscopic and sub-microscopic concepts through dynamic learning experiences, resulting in deeper conceptual understanding. Research also shows that ILMs support independent learning processes and allow students to review materials or topics as needed (Ang, 2020; Schweiker & Levonis, 2023). Furthermore, although independent learning can improve learning outcomes, it is also necessary to consider the differences in learning styles and learning motivations of each student (Hibbard, Sung, & Wells, 2015; Koć-Januchta, Höffler, Prechtl, & Leutner, 2020). Furthermore, the direct feedback feature in ILMs can guide learning and enhance retention (DeVore et al., 2017). It has been shown that adaptive tools effectively meet diverse student needs and optimize the overall educational experience in chemistry.

High-quality interactive learning materials (ILMs) play a crucial role in promoting student engagement and strengthening conceptual mastery in chemistry education by incorporating multimodal elements such as animations and simulations. These resources connect the microscopic and macroscopic levels of chemistry, offering students dynamic opportunities for deeper conceptual exploration. Prior studies have shown that ILMs can increase attention and support self-directed learning, enabling students to revisit challenging topics at their own pace and pursue areas that spark their individual interest (Ang, 2020; Schweiker & Levonis, 2023). However, although self-pacing has been linked to improved academic performance, the effectiveness of ILMs depends heavily on how well they are aligned with learners' characteristics and cognitive demands; interactivity alone does not guarantee success without a sound instructional design that takes into account variations in learning styles and motivational factors (Hibbard et al., 2015; Koć-Januchta et al., 2020). Additionally, embedding immediate feedback within ILMs provides scaffolding that directs the learning process and reinforces knowledge retention (DeVore et al., 2017). Evidence further suggests that adaptive learning technologies are particularly effective in meeting students' heterogeneous needs and enhancing the overall quality of chemistry education.

Despite the growing body of literature on interactive learning materials (ILMs) and differentiated instruction (DI), significant gaps remain in understanding students' perceptions of these constructs as an integrated whole, encompassing dimensions such as relevance, conceptual ease, engagement, motivation, and effectiveness. Much of the existing research has examined isolated outcomes, such as achievement or motivation, without holistically addressing how students perceive their overall learning experiences with ILMs (Cullipher et al., 2015; Sinaga et al., 2019). Moreover, baseline data regarding students' prior experiences with ILMs, including their frequency and modes of usage, are often underreported, even though such information is essential for interpreting perceived educational needs (Winkelmann et al., 2017). Equally important, the field still lacks comprehensive insights into the diversity of learning-style preferences, particularly hybrid or mixed profiles that students often self-identify. This issue is especially salient in chemistry education, where students face unique challenges in grasping abstract, multi-representational concepts that require different modalities of engagement (Johnson et al., 2019). Without adequate attention to these complex learner profiles, the pedagogical potential of ILMs to bridge abstract chemistry concepts and students' diverse cognitive approaches remains underutilized. Furthermore, studies that integrate quantitative assessments of perception with qualitative narratives, which can provide contextual explanations of how ILMs influence day-to-day learning, are scarce, underscoring the urgent need for further exploration in this area (Banks et al., 2015; Zowada et al., 2018). Addressing these gaps is pivotal to refining ILMs and DI strategies so that they effectively respond to both the cognitive and affective demands of chemistry learning, ultimately enhancing student comprehension and engagement.

This study seeks to address these gaps by introducing several innovative elements into the investigation of ILMs and DI. First, it employs a comprehensive instrument designed to capture students' baseline experiences and perceived needs while simultaneously examining core perceptual dimensions such as motivation, engagement, and effectiveness (da Silva et al., 2022). Second, it systematically documents students' learning-style profiles in detail, including hybrid combinations articulated by students themselves, thereby avoiding the common tendency to collapse diverse profiles into overly broad categories (Yarris et al., 2015). This attention to mixed profiles is pedagogically significant in chemistry education because learners often require multiple representational modes (symbolic, macroscopic, and sub-microscopic) to understand complex phenomena, and their preferred pathways may not be reducible to a single style. Third, the study combines descriptive statistics with qualitative analysis of open-ended responses, enabling a nuanced interpretation that reveals not only "how high" students' perceptions are but also "why" and "in what ways" ILMs designed with DI principles are valued in the context of chemistry learning (Kozleski, 2017). Such a mixed-methods approach enhances our understanding of the interplay between students' perceptions and their learning experiences with ILMs, offering clearer pedagogical directions for fostering inclusive and effective chemistry instruction (Bush et al., 2020).

Consequently, this study sets out several objectives: first, to examine students' prior experiences with and their perceived need for ILMs in the context of chemistry; second, to outline students' perceptions across the five dimensions previously identified; third, to document learning style preferences, including hybrid profiles, as a foundation for differentiated instructional design; fourth, to investigate descriptive connections between students' perceptions and the diversity of learning styles; and finally, to gather rationales, experiences, and recommendations through open-ended responses that complement and enrich the quantitative findings. Collectively, these aims prioritize students' perspectives in the investigation while providing practical implications for designing effective instruction materials.

▪ METHOD

Participants

The study population consisted of all students enrolled in the Chemistry Education Program at Universitas Negeri Makassar, Indonesia. The sample included 62 students, randomly selected from four different cohorts. A random sampling technique was employed, ensuring that each student had an equal chance of being selected. Involving multiple cohorts was intended to capture variations in students' learning experiences, particularly in exposure to diverse interactive learning materials (ILMs).

Research Design and Procedures

This study employed a mixed-methods design with a descriptive approach. The research was conducted in three main stages. First, the questionnaire was developed and pilot-tested, including validity and reliability testing. Second, data collection was carried out over a period using an online survey distributed through Google Forms, in which students responded to both Likert-scale items and open-ended questions. Third, quantitative and qualitative data were analyzed separately and then integrated to provide a comprehensive interpretation of students' perceptions.

In this context, students had prior experience with various ILMs across different courses, but this experience was not uniform for all participants. The ILMs encountered included animations, interactive videos, virtual laboratory simulations, app-based quizzes, and digital modules enriched with visuals or audio explanations. Differentiated instruction was operationalized through the provision of explicit alternative learning pathways, enabling students to engage with content through animated visualizations, exploratory simulations, or narrative explanations, depending on their preferred learning styles. Interpretation followed the category classification in Table 1.

Table 1. Variables, scoring, and categorization aspects

Mean Range	Category	Description
4.21 – 5.00	Very High	Strong, consistent positive perception; high readiness for implementation.
3.41 – 4.20	High	Positive perception; majority supportive; implementation highly feasible.
2.61 – 3.40	Moderate	Mixed or moderate perception; requires strengthening of design & communication.
1.81 – 2.60	Low	Generally negative perception; the approach requires reevaluation.
≤ 1.80	Very Low	Strongly negative perception; the approach is unsuitable or requires redesign.

Instruments

The main instrument was a student perception questionnaire with a five-point Likert scale, covering six aspects: (1) conceptual comprehension, (2) differentiation and learning styles, (3) relevance, (4) motivation and engagement, (5) learning effectiveness, and (6) preliminary experience. Reliability testing yielded a Cronbach's Alpha coefficient of 0.87, indicating high internal consistency. The second part of the instrument consisted of open-ended questions designed to elicit students' experiences with ILMs and their views on the need for such materials in chemistry learning. Students were also asked to self-report their dominant learning style (visual, auditory, kinesthetic, or a combination). Students' learning-style profiles were obtained using the '*Tes Gaya Belajar Minat Pintar*,' an online learning-style assessment provided by the *Aku Pintar* platform (https://akupintar.id/mp/tes-gaya-belajar). The instrument has been supervised and reviewed by professional psychologists affiliated with Aku Pintar, ensuring that the measurement framework and item structure are valid for educational and developmental purposes. This tool generates learning-style classifications from students' responses across visual, auditory, and kinesthetic dimensions, making it suitable for identifying hybrid learning tendencies common among chemistry learners.

Data Analysis

Quantitative data were analyzed using descriptive statistics to calculate the mean scores for each perception aspect, which were then classified into three categories: low (1.00–2.33), moderate (2.34–3.66), and high (3.67–5.00). Comparative analyses were conducted to examine differences in perceptions across learning style groups. Qualitative data were analyzed thematically, with open-ended responses coded and grouped into recurring themes. The integration of quantitative and qualitative findings enabled a more comprehensive interpretation, with numerical scores reinforced by students' narratives that explained how ILMs shaped their learning experiences.

Inferential statistical analyses were performed to examine whether students' perceptions of the Interactive Learning Materials (ILMs) differed across learning-style groups. Because the perception data were collected using Likert-type scales and preliminary screening using the Shapiro–Wilk test indicated non-normal distributions in several learning-style groups, a non-parametric approach was deemed more appropriate. Therefore, the Kruskal–Wallis H test was used to compare median perception scores across seven learning-style categories: Visual (V), Auditory (A), Kinesthetic (K), Visual–Kinesthetic (V–K), Visual–Auditory (V–A), Kinesthetic–Auditory (K–A), and Visual–Auditory–Kinesthetic (V–A–K). Only respondents with valid and classifiable learning-style data were included in this inferential analysis. Sixteen respondents provided ambiguous or incomplete learning-style information (e.g., "ya," "iya," or paragraph-length diagnostic text), leaving 46 complete cases for analysis. Kruskal–Wallis tests were conducted for the overall perception score and for each of the six perception dimensions: preliminary experience/relevance, need/relevance, conceptual comprehension, differentiation/learning style, motivation, and effectiveness.

▪ RESULT AND DISSCUSSION

Distribution of Learning Styles

Chemistry learning requires students to engage with abstract concepts such as molecular structures, particle interactions, and submicroscopic phenomena, which are often difficult to visualize. These difficulties become more pronounced when instruction relies on conventional delivery methods that provide insufficient representational support to help students construct understanding (Cullipher, Sevian, & Talanquer, 2015; Johnson, Meyers, Hyme, & Leontyev, 2019). Therefore, examining students' perceptions of interactive learning materials (ILMs) designed with a differentiated approach is essential for understanding how variations in learning modalities can be more effectively supported within the context of complex chemical content.

Table 2. Consolidated distribution of students' learning styles used for inferential analysis (N = 46)

Learning Style Category	Description	Frequency (n)	Percentage (%)
K (Kinesthetic)	Dominant kinesthetic preference	12	26.09
V (Visual)	Dominant visual preference	10	21.74
A (Auditory)	Dominant auditory preference	5	10.87
V–K (Visual–Kinesthetic)	Hybrid visual–kinesthetic preference	11	23.91

V–A (Visual–Auditory)	Hybrid visual–auditory preference	4	8.70
K–A (Kinesthetic–Auditory)	Hybrid kinesthetic–auditory preference	1	2.17
V–A–K (Multimodal)	Triple-modality preference	3	6.52
Total	—	**46**	**100%**

Note: The full survey dataset included 62 respondents; however, only 46 students provided complete and classifiable learning-style data. Therefore, inferential statistics were conducted using only complete cases.

Table 2 presents the distribution of students' learning-style categories used for inferential analysis. Of the 62 survey respondents, 46 students provided valid, classifiable learning-style data and were grouped into seven major categories. The most prevalent categories were Visual–Kinesthetic (V–K), representing 11 students (23.91%), and Kinesthetic (K), representing 12 students (26.09%), indicating that a considerable proportion of students rely on kinesthetic elements in their learning, either as a single dominant mode or in combination with visual input. The Visual (V) category included 10 students (21.74%), while the Auditory (A) category included five students (10.87%). The remaining hybrid categories Visual–Auditory (V–A), Kinesthetic–Auditory (K–A), and Visual–Auditory–Kinesthetic (V–A–K), comprised smaller proportions of the sample: 8.70%, 2.17%, and 6.52%, respectively. Overall, the table highlights substantial variability in students' learning-style profiles, which serves as the basis for subsequent inferential analyses.

Smaller clusters in the sample consisted of Visual–Auditory learners (8.70%), Kinesthetic–Auditory learners (2.17%), and Multimodal Visual–Auditory–Kinesthetic learners (6.52%). Although numerically less common, these groups reflect important hybrid modality preferences that remain pedagogically relevant, particularly the need to blend verbal explanations, auditory cues, and multimodal representations within instruction. The presence of these minor categories, alongside the more dominant Kinesthetic, Visual, and Visual–Kinesthetic groups, underscores the heterogeneous composition of the cohort's learning styles and illustrates the authentic, self-reported variability captured by the learning-style instrument.

Overall, 58.7% of students ($n = 27$) reported learning styles that included kinesthetic elements (K, V–K, K–A, or V–A–K). In comparison, 58.7% also reported visual elements ($n = 27$), and 30.4% reported auditory elements ($n = 14$). These overlapping distributions indicate that most students exhibit multimodal learning tendencies rather than strictly unimodal preferences, with kinesthetic and visual modalities emerging as the dominant combination in this sample. This pattern indicates that most students exhibit multi-modal learning tendencies, with kinesthetic and visual preferences forming the dominant combination. Similar distributions have been reported in previous studies, which note the prevalence of multi-modal preferences among learners in science-related disciplines (Curley, Wu, & Svirskis, 2018; Jain & Sharma, 2023). The prominence of kinesthetic and visual elements in the present study highlights the importance of providing learning materials that incorporate both dynamic visualizations and opportunities for active engagement, particularly given the abstract representational demands of chemistry content."

In the open-ended responses, students highlighted how ILMs helped them grasp abstract concepts. One student noted, '*For example, when learning about molecular* *shapes, interactive learning materials helped visualize them so they became easier to understand*.' Others emphasized the need for more flexible interactivity, such as, '*Sometimes the simulation feels too guided; I want more opportunities to try it on my own.*' These reflections show that differences in learning preferences also extend to desired levels of autonomy in exploration. The pedagogical implication of these findings is clear: interactive learning materials must be designed to accommodate heterogeneity. Materials that offer only a single channel of delivery, for example, text-heavy lectures or purely verbal instruction, risk alienating large segments of the student population. Instead, ILMs should provide multiple entry points: simulations and hands-on virtual activities for kinesthetic learners, animations and diagrams for visual learners, and narrated explanations or discussions for auditory learners. By allowing learners to navigate through different pathways toward the same outcome, ILMs embody the principle of differentiated instruction. Finally, the distribution of learning styles provides a compelling rationale for why students rated the Differentiation & Learning Styles aspect highly (M = 4.17 in Figure 2). Students' awareness of their own profiles and their positive response to ILMs that accommodate those preferences demonstrate that differentiated design is not an abstract pedagogical theory but a lived necessity in this cohort. In sum, the evidence from Table 2 and Figures 3a–3b shows that learning diversity is the norm, and ILMs succeed precisely because they can meet this diversity head-on.

Students' Perceptions of Interactive Learning Materials: Integrated Quantitative and Qualitative Findings

To gain a comprehensive understanding of students' perceptions regarding the use of interactive learning materials (ILMs) with a differentiated approach, it is necessary to integrate both quantitative ratings and qualitative reflections. While numerical scores provide an overview of students' attitudes across specific aspects, qualitative responses add explanatory depth by revealing the reasons behind those perceptions. The following section presents the combined analysis, highlighting mean scores alongside representative student comments to offer a more nuanced interpretation of their experiences.

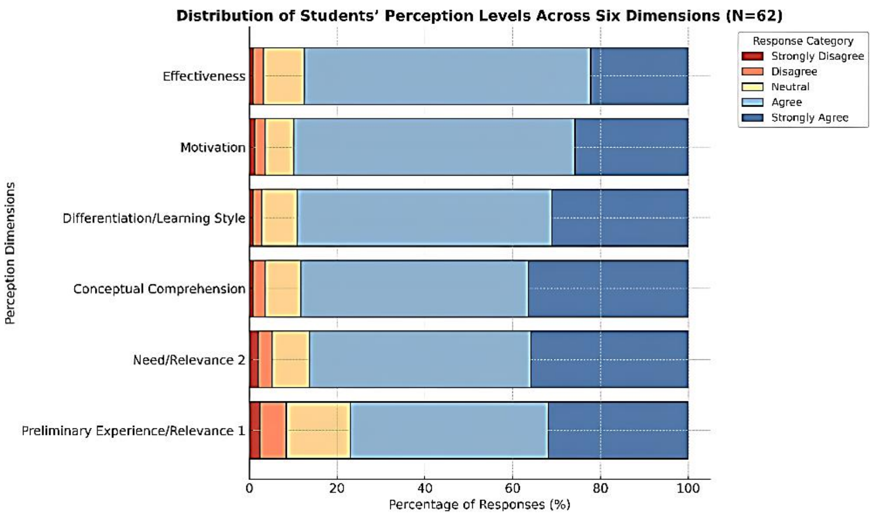

Figure 1. Distribution of students' perception levels across six dimensions

As illustrated in Figure 1, students' responses across the six ILM perception dimensions were predominantly positive. For each dimension Preliminary Experience / Relevance, Need / Relevance, Conceptual Comprehension, Differentiation/Learning Style, Motivation, and Effectiveness, over 80% of the responses fell within the Agree and Strongly Agree categories. Only a small fraction of responses indicated neutrality or disagreement, suggesting a consistently favorable evaluation of the ILMs' design, relevance, and learning support. This overall pattern reinforces the descriptive findings that students perceived the ILMs as effective tools for improving understanding and engagement in chemistry learning.

Table 3. Integrated table of perception scores & student quotes

Perception Aspect	Mean (Category)	Representative Student Quotes
Conceptual Comprehension	4.20 (High)	*"Animations and simulations make it easier for me to understand molecular structures and reactions."*
Differentiation & Learning Styles	4.17 (High)	*"I am a visual learner, and interactive materials give me diagrams and animations."* / *"My style is kinesthetic, and I like it when I can try simulations myself."*
Relevance & Need	4.15 (High)	*"Interactive materials are aligned with students' needs today and keep up with technological development."*
Motivation & Engagement	4.11 (High)	*"Interactive quizzes with immediate feedback make me more excited about learning chemistry."*
Learning Effectiveness	4.06 (High)	*"I achieved better results after using simulations, but the effect is not consistent since not all lecturers use ILMs."*
Preliminary (Experience & Need)	3.98 (High – lowest relative)	*"They are rarely applied, even though they are very helpful. They should be used in every chemistry course."*

The highest mean score was found in Conceptual Comprehension (M = 4.20). As highlighted in Table 3, students emphasized that "*animations and simulations make it easier to understand molecular structures and reactions.*" This qualitative evidence confirms that ILMs directly address one of the most persistent challenges in chemistry education, the abstractness of its concepts, by making invisible processes more tangible and accessible.

The aspect of Differentiation & Learning Styles (M = 4.17) also received a high score, supported by student comments such as, "*I am a visual learner, and interactive materials give me diagrams and animations,*" and "*My style is kinesthetic, and I like when I can try simulations myself.*" These reflections underscore the importance of ILMs in accommodating diverse learning preferences, allowing students to engage through multiple modalities rather than being constrained to a single, uniform approach. Similarly, the Relevance & Need aspect (M = 4.15) was supported by remarks highlighting the alignment of ILMs with modern educational demands, confirming that students regard them as not merely useful but essential in contemporary higher education.

The Motivation & Engagement (M = 4.11) aspect indicates that ILMs have a substantial affective impact. As Table 3 illustrates, students reported that "*interactive quizzes with immediate feedback make me more excited about learning chemistry.*" This demonstrates that ILMs not only improve comprehension but also sustain interest and encourage active involvement, thereby transforming the classroom experience from passive to participatory. By contrast, Learning Effectiveness (M = 4.06) was lower than comprehension and motivation. Students explained this by noting, "*I achieved better results… but the effect is not consistent since not all lecturers use ILMs.*" This highlights that effectiveness depends on consistent implementation: ILMs have demonstrated potential, but their benefits cannot be fully realized without systematic integration across courses. The lowest relative mean was observed in Preliminary Experience & Need (M = 3.98). As seen in Table 3, students stated that "*they are rarely applied, even though they are very helpful. They should be used in every chemistry course.*" This result points to an implementation gap: while students highly value ILMs, their exposure remains uneven, limiting the overall impact on their learning experience.

The variation in scores across aspects also reflects inconsistencies in ILM implementation. Although students benefit from interactive features, the effectiveness depends on how instructors integrate ILMs into their teaching. Variations in digital readiness, access to technological infrastructure, and differing instructional beliefs contribute to uneven student experiences. This suggests that successful use of ILMs requires both strong material design and institutional support for consistent implementation.

This study addresses notable gaps in the literature on interactive learning materials (ILMs) and differentiated instruction (DI) by introducing several innovative elements. First, it utilizes a comprehensive instrument that captures students' baseline experiences and perceived needs while examining relevant dimensions of perception such as motivation, engagement, and perceived effectiveness (da Silva, Freitas Júnior, Ribeiro Silva, & Carvalho Nunes, 2022). Second, it meticulously documents students' learning-style profiles, including mixed combinations articulated by students, thereby avoiding the collapse of diverse profiles into overly broad categories (Yarris et al., 2015). Third, the study combines descriptive statistics with qualitative analysis of open-ended responses, enabling a nuanced interpretation that seeks to unveil not just "how high" perceptions are, but also "why" and "in what ways" ILMs designed with DI principles are valued in the context of chemistry learning (Kozleski, 2017). This mixed-methods approach is pivotal, as it enhances the understanding of the interplay between students' perceptions and their learning experiences with ILMs, thereby offering clearer directions for pedagogical improvements (Bush, Amechi, & Persky, 2020).

Students' Perceptions by Learning Style Groups

Since students in this study represent a wide range of learning style profiles, it is important to examine whether these differences influence their perceptions of ILMs. Analyzing perception scores by learning style groups provides deeper insight into how multi-modal learners, single-mode learners, and auditory-oriented students experience the benefits and limitations of ILMs. The following section presents a comparative analysis of mean scores across the five most common learning style groups, followed by a discussion of the pedagogical implications.

Table 4. Mean scores of perception aspects by learning style (top 5 groups, N = 46)

Learning Style (n)	Preliminary	Relevance	Comprehension	Differentiation	Motivation	Effectiveness
Kinesthetic (13)	3.69	3.90	3.96	3.98	3.92	3.90
Visual (11)	4.00	4.05	4.14	4.05	4.05	3.98
Kinesthetic-Visual (11)	4.18	4.27	4.32	4.36	4.27	4.24
Visual-Kinesthetic (6)	4.29	4.17	4.42	4.29	4.08	4.13
Auditory (5)	3.80	4.25	4.25	4.25	4.15	4.25

Table 4 shows that students with a purely kinesthetic learning style reported the lowest perception scores across all aspects, particularly in learning effectiveness (M = 3.90). In contrast, kinesthetic–visual hybrid learners rated the same aspect substantially higher (M = 4.24), reflecting more substantial alignment between the ILM features and their preferred modalities. This pattern suggests that while ILMs offer interactive elements, the existing activities may not fully meet the expectations of kinesthetic-only learners who typically require more flexible, exploratory, and manipulable forms of engagement. The gap between their preferences and the available interactive features is also reflected in the qualitative responses, where several students expressed a desire for more open-ended, hands-on interaction.

By contrast, students identifying as Kinesthetic only (M = 3.69–3.98) displayed the lowest relative means, particularly in the Preliminary aspect (M = 3.69). This may reflect a perception that their learning style is not fully supported, as many ILMs tend to prioritize visual or auditory channels (Khanal et al., 2019). The relatively lower scores among kinesthetic-only learners suggest that, while ILMs provide some interactive opportunities, the tactile or manipulative dimension remains underdeveloped compared to the visual and auditory features (Hernandez, Vasan, Huff, & Melovitz-Vasan, 2020). Research indicates that kinesthetic learners, who acquire information through physical processes such as touch and movement, often find traditional instructional methods inadequate (Min Swe & Wh, 2020; Palupi, Suwartono, & Sukawati, 2024). Expanding ILMs to include more virtual labs, manipulative simulations, and exploratory tools would better meet their needs and enhance their engagement with the curriculum (Hernandez et al., 2020). Such adaptations are crucial to create a more balanced educational experience that acknowledges and supports varied sensory modalities (Ayub, Karim, & Laraib, 2023; Ruffing, Wach, Spinath, Brünken, & Karbach, 2015)

Interestingly, the Auditory group (M = 3.80–4.25) reported relatively high ratings in Effectiveness (M = 4.25) and Relevance (M = 4.25). This indicates that, even though auditory learners are a minority within the cohort, they still benefit from ILMs that offer features such as narrated explanations, discussion opportunities, and verbal feedback. Their strong rating for effectiveness suggests that when such features are present, they translate directly into improved learning outcomes. The Visual group (M = 3.98–4.14) rated comprehension highly (M = 4.14), consistent with their preference for visual clarity in representations. Their overall high but not extreme scores suggest that while ILMs meet their needs, they may not derive the same synergistic benefit as multi-modal learners who combine visual and kinesthetic strengths. Taken together, these findings emphasize that while all groups benefit from ILMs, the multi-modal learners (especially kinesthetic-visual hybrids) perceive the greatest advantages. The results also highlight an important gap: kinesthetic-only learners feel less supported, pointing to the need for richer interactive and manipulative features. At the same time, though fewer in number, auditory learners demonstrate that when verbal/narrative support is embedded, it translates into tangible effectiveness.

Table 4 reveals that students with a purely kinesthetic learning style reported lower perception scores across all aspects compared to their peers with visual or kinesthetic–visual hybrid preferences. For example, their mean effectiveness score was only 3.90, whereas kinesthetic–visual learners rated this aspect at 4.24. This discrepancy indicates a gap between kinesthetic learners' expectations and the experiences ILMs actually provide. Students' open-ended responses further illustrate this mismatch. One respondent stated: "*Sometimes the simulation feels too guided; I want more opportunities to try it on my own.*" This quote underscores that kinesthetic learners expect more open-ended exploration, whereas many ILMs tend to be highly structured and visually dominant. Another student remarked, "*I find it effective because with animations, simulations, and direct exercises, I can understand faster.*" While acknowledging the benefits of simulations, this response also emphasizes the importance of direct, hands-on engagement that goes beyond mere visualization. Taken together, these findings suggest that although ILMs are highly beneficial for multimodal learners, students with purely kinesthetic preferences feel underserved, as their need for active, hands-on learning is not fully accommodated. This highlights that the success of ILMs depends not only on the inclusion of interactive features but also on the extent to which such interactivity enables genuine exploration aligned with students' learning styles.

These findings emphasize the need for ILMs that not only acknowledge but also operationalize learner heterogeneity through concrete design features. In particular, the relatively low ratings from kinesthetic-only learners indicate that future ILMs must provide richer opportunities for tactile-like, exploratory interaction. Several actionable features can be incorporated: (1) virtual laboratory simulations equipped with free-exploration or sandbox modes, allowing students to manipulate variables, run multiple trials, and observe outcomes independently; (2) interactive molecule-building tasks using drag-and-drop or 3D rotation tools that let learners assemble molecular structures rather than merely viewing them; (3) gesture-based or movement-simulated interactions such as rotating models, toggling bond formations, or simulating particle collisions; (4) scenario-based tasks with manipulable objects, where students can experiment with reaction conditions or energy changes; and (5) adaptive branching pathways that adjust interactivity levels based on learner input, offering more hands-on tasks to those who prefer kinesthetic engagement.

Inferential Analysis of Learning-Style Differences

To determine whether the mean differences shown in Table 4 were statistically significant, a Kruskal–Wallis H test was conducted using the valid subset of 46 respondents. The results (Table 5) showed that no statistically significant differences existed in perception scores across the seven learning-style groups,

$H(6, 46) = 4.72$, $p = .58$. Similarly, all six perception dimensions: Preliminary Experience / Relevance, Need / Relevance, Conceptual Comprehension, Differentiation /

Learning Style, Motivation, and Effectiveness, yielded non-significant p-values ranging from .38 to .92. This indicates that while minor variations were observed descriptively, these differences were not statistically meaningful. In other words, students' positive perceptions of ILMs were consistent across learning-style categories, suggesting that the materials were inclusively designed to effectively support diverse learners.

Table 5. Kruskal–Wallis test results for differences in perception scores across learning-style groups

Perception Aspect	H	p
Overall Perception Score	4.72	0.58
Preliminary Experience / Relevance 1	6.32	0.39
Need / Relevance 2	3.32	0.77
Conceptual Comprehension	1.97	0.92
Differentiation / Learning Style	2.98	0.81
Motivation	6.36	0.38
Effectiveness	5.06	0.54

The absence of statistically significant differences among learning-style groups reinforces the notion that interactive learning materials (ILMs) with differentiated pathways successfully meet the needs of heterogeneous learners. Regardless of individual learning-style preferences: visual, auditory, kinesthetic, or hybrid, all groups perceived the ILMs positively. This finding aligns with the pedagogical premise of differentiated instruction, where instructional design flexibility and multimodal representation allow students to access content through multiple sensory channels (Boelens, Voet, & Wever, 2018; Valiandes, 2015). While quantitative data suggest equivalence of experience, qualitative reflections still indicate that certain groups, particularly kinesthetic-only learners, seek richer opportunities for active, manipulative exploration. Therefore, even though no statistical difference was detected, pedagogical refinement remains necessary to address the experiential preferences highlighted by specific learner groups.

While the findings of this study provide meaningful insights into students' perceptions of ILMs with a differentiated approach, they should be interpreted with caution due to certain limitations. Most notably, the sample size was relatively small (N = 62) and drawn from a single institution, which restricts the generalizability of the results. The patterns identified, such as lower satisfaction among kinesthetic-only learners and the perceived advantages of multimodal learners, may not fully reflect the experiences of chemistry education students in other contexts. Future studies with larger and more diverse samples, ideally involving multiple universities, are necessary to validate and extend the conclusions drawn here.

▪ CONCLUSION

The findings of this study demonstrate that Interactive Learning Materials (ILMs) developed using a differentiated instruction approach effectively support students' understanding of abstract chemistry concepts. Students' overall perceptions of the ILMs were high across all measured dimensions, including preliminary experience, relevance, conceptual comprehension, differentiation, motivation, and effectiveness. Furthermore, the inferential Kruskal–Wallis test revealed no statistically significant differences in perception scores across the seven learning-style groups (H(6, 46) = 4.72, p = .58). This suggests that the ILMs provided an equally positive and engaging learning experience for students with diverse learning-style profiles: visual, auditory, kinesthetic, or hybrid. In practice, these results emphasize the importance of designing multimodal, flexible ILMs that accommodate heterogeneous learner preferences. Future ILM development should integrate more exploratory and kinesthetic-oriented features, such as virtual laboratory simulations, drag-and-drop molecular construction tasks, and manipulable 3D models, to better support kinesthetic learners while maintaining strong visual and auditory scaffolding. In doing so, ILMs can function not only as interactive visual tools but as inclusive learning environments that foster active, differentiated, and meaningful engagement for all students.

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