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RESEARCH ARTICLE

A Comparative Analysis of Experts' and Elementary and Secondary School Teachers' Perceptions of the Intrinsic and Utilitarian Importance of Science Simulation

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ABSTRACT

This study aims to analyze the perceived gap between the educational value (intrinsic importance) of science simulation content and its practical value (utilitarian importance) required in actual classrooms within the rapidly changing educational environment of the digital transformation era. Based on this analysis, the study proposes directions for the effective development of science simulation content. A survey was conducted with 81 science education experts and K–12 teachers, and the data were analyzed using Importance–Performance Analysis (IPA), analysis of variance (ANOVA), and independent-samples t-tests.

The key findings are as follows. First, perceptions of intrinsic importance in the development of science simulations differed across participant groups. Experts prioritized alignment with the curriculum and virtual inquiry activities, whereas elementary teachers emphasized experience with variable manipulation and repeated trials, and secondary teachers identified support for concept visualization as the most critical element. Second, significant differences were observed between elementary and secondary teachers in their perceptions of utilitarian importance during classroom implementation. Elementary teachers, reflecting the characteristics of activity-centered instruction, placed high value on diverse variable manipulation and Dialogic (interactive) feedback. In contrast, secondary teachers, influenced by concept-centered instruction, tended to perceive simulations primarily as supplementary learning materials rather than inquiry tools. Third, the IPA results identified several core teaching and learning elements requiring priority consideration, including the scientific accuracy of conceptual visualization, the diverse manipulation of variables, and the user-friendliness of digital device operation. Conversely, diverse assessment types and dialogic (interactive) feedback were perceived as relatively lower in both intrinsic and utilitarian importance, suggesting that these elements may warrant further consideration in future development.

In conclusion, science simulation content development should move beyond uniform, developer-centered dissemination. Instead, differentiated development strategies are required that reflect grade-level instructional goals—such as activity-centered learning for elementary education and logical rigor for secondary education—along with the integration of intelligent assessment and feedback systems.

Keywords : Science Inquiry, simulation, intrinsic importance, utilitarian importance, IPA analysis

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Introduction

As social change accelerates with advances in digital technology, the environment educators and learners face is undergoing a transformation, as artificial intelligence, immersive technologies, and cloud computing reshape daily life and the broader educational landscape. This rapid digital proliferation is redefining the competencies required for future society while simultaneously transforming pedagogical methods, unlocking educational opportunities that were previously unattainable through traditional teaching and learning approaches (OECD, 2025). In particular, immersive digital technologies are increasingly being integrated into education, as they help learners understand complex phenomena, render abstract or inaccessible concepts tangible, and provide iterative interactive experiences (Forsström et al., 2025). Simulations, such as virtual laboratories that utilize these immersive technologies, allow students to conduct experiments in controlled virtual environments, thereby providing opportunities for scientific inquiry free from resource constraints or safety concerns (Hillmayr et al., 2020).

Previous studies applying digital simulations to educational activities reveal that visualizing molecular structures in 3D enables learners to understand chemical reactions and the spatial orientation of molecules (Sırakaya & Sırakaya, 2022). Furthermore, visualizing cellular structures, ecosystems, and animal behavior provides practical opportunities in virtual spaces, thereby extending learners' experiences into the non-visible realm (Pellas et al., 2020). In addition, it has been suggested that these technologies can enhance student interest and satisfaction by enabling exploration of activities difficult or dangerous to replicate in laboratories, such as deep-sea exploration, investigations in zero-gravity environments, or observing nuclear reactions, as well as studying unrealistic phenomena (Yakubova et al., 2023; Zhang & Wang, 2021). In a similar vein, research indicates that virtual environments effectively enhance learners' inquiry abilities by visualizing abstract scientific concepts difficult to observe with the naked eye (Han et al., 2025) or by implementing experiments in virtual spaces that are challenging to perform in schools due to risks or cost issues (Kim & Kim, 2024). Above all, allowing learners to freely manipulate variables and engage in repeated inquiry activities within virtual environments increases opportunities to transform students' misconceptions into scientific concepts (Shin & Park, 2023) and has been reported to positively influence the cultivation of scientific attitudes and academic achievement (Lee & Hong, 2017).

Digital-based simulations offer advantages for use in various science learning contexts. Consequently, infrastructure for conducting digital-based inquiry activities, such as smart science labs, is being expanded, while diverse simulation content is being developed and disseminated. However, research conducted with elementary, middle, and high school teachers revealed that, despite the availability of platforms like Intelligent Science Lab ON, which offer diverse science learning simulations, approximately 73% of respondents reported not using them in their classes (Byeon, 2024). In other words, the quantitative expansion of simulation content and the creation of utilization environments are not translating into actual classroom use, and the utilization of science inquiry simulations in school settings remains low.

Despite the high potential of digital-based simulation learning materials for educational effectiveness, they are often used selectively or with limited functionality, depending on the teacher's perceived practicality and the specific classroom context (Chen & Chen, 2025; de Jong et al., 2021). These findings suggest that the underutilization of simulations in classroom settings may be influenced more by teachers' perceptions and judgments formed during instructional implementation than by inherent technological limitations; however, empirical research examining this issue remains limited.

Teachers may not actively incorporate content such as digital simulations into their lessons not only because of physical constraints but also because they struggle to integrate them appropriately into the introduction, development, and conclusion phases of instruction (Kwak et al., 2025). Furthermore, teachers in the field expect simulations to realistically implement scientific inquiry activities in virtual environments. However, they often perceive that the content actually provided either fails to sufficiently implement the inquiry process or lacks realism, making it difficult to use in class (Byeon, 2024). This suggests a potential cognitive gap between the characteristics of currently distributed science simulation content and the practical perspectives teachers require in actual classrooms. Therefore, beyond the quantitative expansion of digital simulations, it is necessary to deeply analyze teachers' perceptions—the primary agents integrating simulations into lessons—and to redefine the direction for developing practically usable content. To achieve this, it is necessary to clearly identify the differences between the intrinsic importance—the essential value of science inquiry simulations as perceived by teachers in the field—and the utilitarian importance—the value prioritized in actual classroom settings.

Accordingly, this study employs the Importance-Performance Analysis (IPA) methodology to explore the strategic direction for the development of science simulation content. By examining the intrinsic and utilitarian importance perceived by both expert groups and field teachers, this study seeks to identify essential elements for the creation and utilization of simulation-based learning materials. Furthermore, through this dual-importance analysis, we propose effective planning directions to minimize the discrepancy that often arises when content development and instructional implementation are decoupled. To address these objectives, the following research questions are proposed:

First, do science education experts and classroom teachers agree on the intrinsic importance that should be considered when developing science simulations?

Second, do elementary and secondary school teachers share the same understanding regarding the utilitarian importance that should be considered when implementing science simulations in lessons?

Third, what elements should be prioritized in content development based on the analysis of the intrinsic and utilitarian importance of science simulations?

Theoretical Background

Simulation content supporting science learning is currently operated as Software as a Service (SaaS) across various platforms. SaaS refers to a cloud-based software model that delivers applications to end users via the internet (AWS, 2025). Unlike traditional download-based methods, SaaS is a software-as-a-service that is delivered via networks and accessed via the web, tailored to user needs (Hwang et al., 2014). Therefore, to be delivered on demand via a platform, it must be developed in a standardized format. For ease of development, it is often created using identical plots and closed content types. Consequently, since the various simulation content formats currently used in schools are software services produced by developers and delivered via platforms, an analysis of alignment between developer-side value and userside value is necessary.

In science learning, digital simulations are crucial for enabling experiences in virtual environments that are inaccessible or unsafe in traditional classrooms or science labs, or for simulating experimental processes (Yakubova et al., 2023). Furthermore, simulations are significant for visualization, as they can prevent misconceptions arising from abstract concepts or learners' individual mental imagery (Pellas et al., 2020). Moreover, simulations enable repeated experiments and are cost-effective since they do not require physical materials (Hillmayr et al., 2020). They also inherently possess the capability to provide real-time feedback and opportunities for collaborative inquiry due to their digital-based operation (Forsström et al., 2025). In this regard, it is essential to minimize the gap between development and utilization by analyzing the alignment between teachers' perceived values in the context of simulation development and in classroom implementation.

Importance-Performance Analysis (IPA), originally introduced by Martilla and James (1977), has evolved into a robust diagnostic tool in educational research for identifying strategic priorities by analyzing the discrepancy between ideal expectations and actual implementation. IPA analysis has primarily been used in marketing, but it has recently been widely applied across various fields to analyze the gap between user needs and actual usage patterns, thereby deriving priorities for practical improvements (An, 2022; Kim et al., 2019). Also, recent studies suggest that the IPA analysis method is highly effective in visually clarifying the discrepancy between users' ideal expectations and actual performance, and in determining where limited resources should be prioritized(Lee, 2025; Wang & Min, 2024).

Moreover, this methodology has been actively adopted to address the complexities of digital transformation in education. For instance, Yoon and Kyung (2025) utilized IPA to highlight the gap between the perceived importance and actual performance of ICT utilization competencies among elementary school teachers. Similarly, Lee && Jang (2025) applied IPA to identify critical service gaps in the digital competencies of youth workers, while Yoo (2025) employed a similar prioritization approach to determine essential environmental factors for non-face-to-face instruction. These studies collectively demonstrate that IPA is highly effective in visually clarifying where limited resources should be focused within rapidly evolving digital learning landscapes.

In Importance–Performance Analysis (IPA), the analytical space is typically divided into four quadrants based on the relative levels of importance and performance. These quadrants are conventionally interpreted as areas for maintaining strengths, avoiding excessive investment, assigning low priority, and improving priority. This general interpretative framework provides a conceptual basis for categorizing elements according to their relative importance patterns before contextual adaptation in specific research settings. The IPA methodology is a useful tool for identifying strategic priorities by analyzing the gap between two different dimensions of perception. Therefore, IPA is employed to explore the potential discrepancy between the values emphasized during the development of science simulations and those prioritized during their classroom utilization in this study. For this analysis, the researchers operationally defined the axes as ‘Intrinsic importance’ and ‘Utilitarian importance.’ The former represents the inherent educational and technical value—such as scientific accuracy—judged essential during the development phase, while the latter signifies the practical value prioritized for classroom instruction, focusing on usability and situational fitness. By mapping these two dimensions, this study seeks to identify the "decoupling" between the supply of digital content and its practical utility. This approach enables objective observation of the gap between the developmental and instructional spheres, suggesting a future direction for science simulation development.

Materials and Methods

Participants

A survey was conducted with science education experts and elementary and secondary school teachers to investigate the intrinsic importance and utilitarian importance of science simulation content. Teachers were provided with an explanation of the study's purpose and content prior to survey distribution and were asked to respond online only if they voluntarily agreed to participate. Science education experts responded in writing to also gather additional descriptive opinions. This study aims to compare the intrinsic importance that should be considered in the development context of science simulation content and the utilitarian importance that should be considered in the classroom implementation context. Therefore, the intrinsic importance survey was conducted with 73 elementary and secondary school teachers (Table 1) and 8 science education experts to confirm perceptions of the attributes of science simulation content. Conversely, the utilitarian importance survey was administered only to the 73 teachers, excluding the 8 science education experts, to investigate perceptions regarding the practical application of science simulation content in actual science lessons. Survey distribution and result collection were conducted over approximately two months from June to July 2025, using both an online method via the Google Forms platform and written responses.

Table 1. Demographic characteristics of teacher respondents (N = 73)

Category	Subcategory	n	%
Age (years)	20s	9	12.33
	30s	32	43.84
	40s	28	38.36
	50s	4	5.48
Gender	Male	35	47.94
	Female	38	52.05
School Level	Elementary school teachers	24	32.88
	Secondary School teachers	49	67.12

Among secondary school teachers, 11 (22.45%) specialized in physics education, 11 (22.45%) in chemistry education, 16 (32.65%) in biology education, and 11 (22.45%) in earth science education, indicating a low degree of specialization variation. Science education experts with experience in developing or evaluating digital simulations participated. A total of eight professors from teacher training institutions served as experts, with two specialists in each of the following disciplines: physics education, chemistry education, biology education, and earth science education. Among the teacher respondents, secondary school teachers accounted for 67.12%. Given this sample composition, the findings should be interpreted with caution, as secondary school teachers' perceptions may be more strongly reflected in the overall results.

Measurement

The questionnaire, designed to assess perceptions of current elementary and secondary school teachers and science education experts regarding the development and use of science simulation content, was structured around two core domains: intrinsic and utilitarian importance. The sub-measurement categories and elements for each domain were developed through the research team's regular seminars and a literature review on simulation learning content, digital-based learning materials, and instructional competency. The survey was designed with 16 items for intrinsic importance and 16 items for utilitarian importance, each corresponding to the other. All items used a 5-point Likert scale, allowing teachers to respond sequentially regarding their perceived level of importance. The individual core domains were structured to comprise three measurement categories: Science Themes of Science Simulation, Contents Structure of Science Simulation, and Functions of Science Simulation. Each measurement category was subdivided into detailed measurement elements.

The survey comprises 32 items. The measurement category for the science simulation content theme domain measures five elements: Alignment with the curriculum, Support for concept visualization, virtual inquiry activities, Experience with variable manipulation and repeated trials, and Maintaining learner engagement and attention. The measurement category for the content structure domain of science simulation content measures six elements: Design aligned with the textbook, Scientific accuracy of conceptual visualization, Appropriateness for the inquiry process, Authentic virtual activities, Diverse manipulation of variables, and Learner autonomy in exploration. The functional domain of science simulation content is designed to measure five elements: User-friendliness of digital device operation, Flexible 3D manipulation, Use of diverse multimedia resources, Dialogic (interactive) feedback, and Diverse forms of assessment.

The survey questions were initially developed through regular research team seminars and consultations with four science education experts. To ensure content validity, two science education experts and seven field teachers reviewed the questions, yielding a very high Content Validity Index (CVI) of 0.92. The second set of items was developed by incorporating revisions suggested by the expert reviewers. The final questionnaire was confirmed after additional review and modification by the research team. To verify the internal consistency and reliability of the developed questionnaire, Cronbach's α was calculated. Cronbach's α was very high at 0.94, and individual items also showed high reliability, with each item scoring at least 0.70.

Analysis

This study analyzed survey data on respondents' perceptions of the intrinsic and utilitarian importance of science simulation content among 81 participants using SPSS 29.0. Specifically, descriptive statistics and rank analysis were performed for the intrinsic importance and utilitarian importance of science simulation content. First, treating all 81 survey respondents as a single group, the mean values for each measurement category and element were calculated from the responses, and rankings were determined for each measurement category. Furthermore, to determine whether differences in perception of intrinsic importance existed among groups (elementary teachers, secondary teachers, science education specialists), the mean values for each measurement category and factor were calculated. The overall response patterns were examined by comparing the priority rankings across measurement categories.

To identify group effects, a one-way analysis of variance (ANOVA) was performed. During the analysis, some items did not exhibit homogeneity of variance. Therefore, to ensure statistical validity, the combined mean of items within the same category was calculated and analyzed. Accordingly, Welch's one-way ANOVA was performed in this study, accounting for differences in the number of respondents per group, and Games-Howell post hoc tests were conducted.

Next, to verify statistically significant differences in the perceived importance of using science simulations in lessons between elementary and secondary school teachers, an independent-samples t-test was performed based on group membership. Homogeneity of variance was confirmed in the answers of the elementary teacher and the secondary teacher. Finally, an IPA analysis was conducted using all responding teachers as a single group to determine whether field teachers' perceptions of the intrinsic and utilitarian importance of science simulations were consistent or whether any inconsistencies existed. Additionally, an IPA analysis was conducted using the group-specific response results to identify whether differences existed in the patterns of importance perception between elementary and secondary school teachers and in the distribution patterns by group.

Results

Intrinsic Importance of Science Simulation Development between Groups

The perceived intrinsic importance of science simulation content was categorized into three measurement domains: 'Themes of Science Simulation,' 'Content Structure of Science Simulation,' and 'Functions of Science Simulation.' The mean of items within each domain was calculated to analyze importance rankings (Table 2).

Analysis of the measurement categories for intrinsic importance revealed the following order of importance within the 'Themes of Science Simulation' category: Support for concept visualization > Virtual inquiry activities = Experience with variable manipulation and repeated trials > Maintaining learner engagement and attention > Alignment with the curriculum. Within the 'Contents Structure of Science Simulation' category, the following order of importance emerged: Diverse manipulation of variables > Scientific accuracy of conceptual visualization> Authentic virtual activities > Learner autonomy in exploration > Design aligned with the textbook > Appropriateness for the inquiry process. Within the 'Functions of Science Simulation' category, the order of importance was as follows: User-friendliness of digital device operation > Flexible 3D manipulation > Use of diverse multimedia resources > Dialogic (interactive) feedback > Diverse forms of assessment. The factors receiving the highest importance ratings across the three measurement categories were 'Support for concept visualization,' 'Diverse manipulation of variables,' and 'User-friendliness of digital device operation.' This indicates that field teachers and experts recognize these as core elements that should be prioritized when developing science simulation content. Based on the average of all survey respondents, the importance ranking for science simulation development revealed that concept visualization was the primary consideration in the topic category, diverse variable manipulation in the content structure category, and familiarity with digital device usage in the functionality category. To determine whether these responses were consistent across groups of elementary teachers, secondary teachers, and science education specialists, or if group differences existed, we calculated and compared the means for each group.

Within the 'Themes of Science Simulation' category, for elementary school teachers, the order of importance was: Experience with variable manipulation and repeated trials > Maintaining learner engagement and attention = Virtual inquiry activities > Support for concept visualization > Alignment with the curriculum. For secondary school teachers, the order of importance was: Support for concept visualization > Virtual inquiry activities > Experience with variable manipulation and repeated trials > Maintaining learner engagement and attention > Alignment with the curriculum.

Table 2. The importance ratings for science simulation content in intrinsic context

Measurement Category	Measurement Element	Total Group(n=81)		Each Group					
		M (SD)	Rank	EST M (SD)	Rank	SST M (SD)	Rank	UP M (SD)	Rank
Themes of Science Simulation	Alignment with the curriculum	4.68(0.52)	5	4.71(0.55)	5	4.61(0.53)	5	5.00(0.00)	1*
	Support for concept visualization	4.79(0.41)	1*	4.75(0.44)	4	4.78(0.42)	1*	5.00(0.00)	1*
	Virtual inquiry activities	4.75(0.51)	2	4.79(0.42)	2	4.69(0.59)	2	5.00(0.00)	1*
	Experience with variable manipulation and repeated trials	4.75(0.51)	2	4.88(0.34)	1*	4.67(0.59)	3	4.88(0.35)	4
	Maintaining learner engagement and attention	4.70(0.49)	4	4.79(0.42)	2	4.65(0.52)	4	4.75(0.46)	5
Contents Structure of Science Simulation	Design aligned with the textbook	4.43(0.63)	5	4.50(0.66)	6	4.39(0.64)	3	4.50(0.54)	5
	Scientific accuracy of conceptual visualization	4.58(0.70)	2	4.75(0.44)	3	4.51(0.82)	2	4.50(0.54)	5
	Appropriateness for the inquiry process	4.41(0.65)	6	4.58(0.50)	5	4.29(0.71)	6	4.63(0.52)	4
	Authentic virtual activities	4.53(0.71)	3	4.79(0.51)	2	4.37(0.78)	4	4.75(0.46)	3
	Diverse manipulation of variables	4.75(0.49)	1*	4.88(0.34)	1*	4.65(0.56)	1*	5.00(0.00)	1*
	Learner autonomy in exploration	4.47(0.65)	4	4.67(0.64)	4	4.33(0.66)	5	4.75(0.46)	2
Functions of Science Simulation	User-friendliness of digital device operation	4.79(0.47)	1*	4.83(0.38)	1*	4.73(0.53)	1*	5.00(0.00)	1*
	Flexible 3D manipulation	4.64(0.53)	2	4.71(0.55)	2	4.57(0.54)	2	4.88(0.35)	2
	Use of diverse multimedia resources	4.52(0.78)	3	4.71(0.46)	2	4.37(0.91)	3	4.88(0.35)	2
	Dialogic (interactive) feedback	4.31(0.78)	4	4.58(0.58)	4	4.08(0.84)	4	4.88(0.35)	2
	Diverse forms of assessment	4.23(0.79)	5	4.58(0.654)	4	4.06(0.83)	5	4.25(0.71)	5

*: 1st Rank

Note. EST: elementary school teacher, SST: secondary school teacher, UP: university professor

For experts, the order of importance was determined as follows: Alignment with the curriculum = Support for concept visualization = Virtual inquiry activities > Experience with variable manipulation and repeated trials > Maintaining learner engagement and attention. Elementary school teachers recognized variable manipulation and repeated experiences, along with inducing learner attention, as key factors to consider when developing simulations.

In contrast, secondary school teachers perceived supporting concept visualization and developing virtual inquiry activities as key factors to consider during development. Elementary school textbooks are structured around inquiry activities, emphasizing activity-centered instruction (Jang, 2023), while secondary school textbooks emphasize concept learning more than their elementary counterparts. Furthermore, due to curriculum design, the content systems, achievement standards, and content elements learned by elementary and secondary students differ (MOE, 2022). Therefore, teachers at each school level can be seen as having perceptions that reflect the characteristics of the learners participating in classroom activities and the features of the curriculum. Experts responded that supporting concept visualization and virtual inquiry activities are important elements, and they emphasized that curriculum connectivity—which had the lowest priority among the teacher group—should be considered crucial. In other words, despite being composed of four members from elementary teacher training institutions and four from secondary teacher training institutions, science education experts demonstrated perceptions similar to secondary teachers when developing science simulations. Simultaneously, they recognized the curriculum—often overlooked by teachers—as a crucial element.

Looking at the average response results for content structure categories, elementary teachers ranked importance in the following order: Diverse manipulation of variables > Authentic virtual activities > Scientific accuracy of conceptual visualization > Learner autonomy in exploration > Appropriateness for the inquiry process > Design aligned with the textbook. For secondary school teachers, the order of importance was: Diverse manipulation of variables > Scientific accuracy of conceptual visualization > Design aligned with the textbook > Authentic virtual activities > Learner autonomy in exploration > Appropriateness for the inquiry process. For experts, the order of importance varied: Diverse manipulation of variables > Learner autonomy in exploration > Authentic virtual activities > Appropriateness for the inquiry process > Design aligned with the textbook = Scientific accuracy of conceptual visualization.

All three groups identified manipulating various variables as an important factor to consider in simulation content design, but differences emerged among the groups regarding the remaining factors. Notably, elementary teachers and experts showed a strong perception of the importance of realistic virtual activities, while secondary teachers tended to perceive their importance as relatively lower. These results indicate that secondary teachers place greater importance on concept visualization and scientific validity. This likely reflects the practical characteristics of secondary science education, where subject-specific content knowledge is considered crucial.

Analysis of responses regarding functional categories revealed the following importance rankings for elementary school teachers: User-friendliness of digital device operation > Flexible 3D manipulation = Use of diverse multimedia resources > Dialogic (interactive) feedback = Diverse forms of assessment. For secondary school teachers, the importance order was: User-friendliness of digital device operation > Flexible 3D manipulation > Use of diverse multimedia resources > Dialogic (interactive) feedback > Diverse forms of assessment. For experts, the perceived importance ranking was: User-friendliness of digital device operation > Flexible 3D manipulation = Use of diverse multimedia resources = Dialogic (interactive) feedback > Diverse forms of assessment. Regarding functional elements to consider when developing simulations, all three groups ranked familiarity with digital device use as the top priority, with similar rankings for the remaining responses. This indicates that elementary/secondary teachers and experts share a common perspective on simulation functionality.

The survey results on respondents' perceptions by group revealed both similarities and differences in the intrinsic importance to consider when developing science simulations. To verify the statistical significance of these differences, the mean responses for each group were calculated across three categories—simulation topic, content structure, and functionality—and an analysis of variance (ANOVA) was conducted. The analysis revealed significant differences in perceptions across all simulation categories between groups. The effect sizes (η^2) ranged from 0.237 to 0.261, indicating a very large practical effect (Table 3).

Table 3. The result of ANOVA with intrinsic importance between groups

Measurement Category	Group						F	*p*	η^2
	EST		SST		UP				
	M	SD	M	SD	M	SD			
Themes of Science Simulation	4.78	0.31	4.68	0.39	4.93	0.10	7.001	0.002*	0.261
Contents Structure of Science Simulation	4.69	0.38	4.42	0.47	4.69	0.21	4.807	0.016*	0.255
Functions of Science Simulation	4.78	0.31	4.56	0.41	4.78	0.23	3.730	0.039*	0.237

*: $p<0.05$

Note. EST: elementary school teacher, SST: secondary school teacher, UP: university professor
Welch's F test was used due to unequal variances

Specifically, the secondary teacher group tended to perceive the simulation topic, content structure, and functional elements as relatively less important than the elementary teacher and expert groups did. These results can be attributed to differences in the perceptions that secondary teachers hold regarding the purpose of science learning and the use of simulations in their regular teaching practice.

While the opinions of experts and elementary teachers showed some similarities, an independent samples t-test was conducted using the responses of elementary and secondary teacher groups on the sub-elements of the content composition and functional categories of simulations to identify the specific elements where secondary teachers perceived differences in the importance of science simulations (Table 4). In the content composition category, statistically significant differences in perceived importance were found between elementary and secondary teachers for 4 of 6 sub-elements for which importance responses were requested. For these elements, elementary teachers rated them as more important than secondary teachers did. Specifically, elementary teachers rated the importance of Authentic virtual activities, Diverse manipulation of variables, Learner autonomy in exploration, and Appropriateness for the inquiry process higher than secondary teachers. Conversely, no significant difference in perception was found between the two groups for the measurement elements, Design aligned with the textbook, and Scientific accuracy of conceptual visualization.

Table 4. The result of independent group t-test with contents structure in intrinsic importance

Measurement Element	Group				*t*	*p*	Cohen's *d*
	EST		SST				
	M	SD	M	SD			
Design aligned with the textbook	4.50	0.66	4.39	0.64	0.697	1.488	0.169
Scientific accuracy of conceptual visualization	4.75	0.44	4.51	0.82	1.622	1.109	0.365
Appropriateness for the inquiry process	4.58	0.50	4.29	0.71	2.065	0.043*	0.472
Authentic virtual activities	4.79	0.51	4.37	0.78	2.780	0.007*	0.637
Diverse manipulation of variables	4.88	0.34	4.65	0.56	2.099	0.040*	0.494
Learner autonomy in exploration	4.67	0.64	4.33	0.66	2.096	0.040*	0.523

*: $p<0.05$

Note. EST: elementary school teacher, SST: secondary school teacher

Utilitarian Importance for Science Simulation Development between Groups

The perceived importance of utilizing science simulation content was categorized into three measurement domains: 'themes of science simulation,' 'content structure of science simulation,' and 'functions of science simulation.' The mean (M) of items within each domain was calculated to analyze importance rankings (Table 5).

Analysis of the measurement categories for utilitarian importance revealed the following order of importance within the 'Themes of science simulation' category: support for concept visualization > ration activities> Learner attention engagement > Alignment with curriculum > Experience with variable manipulation and repetition. In the content structure of the science simulation category, importance was confirmed in the following order: scientific accuracy of conceptual visualization > Realistic virtual activities = Diverse manipulation of variables > Design linked to textbook content > Learner autonomy in exploration > Appropriateness of the inquiry process. In the Functions of Science Simulation category, importance appeared in the following order: User-friendliness of digital devices > Free three-dimensional manipulation > Use of diverse multimedia > Dialogic (interactive) feedback > Diverse types of assessment. Therefore, 'Support for concept visualization', 'Scientific accuracy of conceptual visualization', and 'User-friendliness of digital devices'. This indicates that elementary and secondary teachers perceive these elements as core considerations that should be prioritized when utilizing science simulation content in their lessons.

In the 'Themes of science simulation' category, for elementary teachers, importance was ranked in the following order: Support for Concept Visualization > Learner autonomy in exploration > Alignment with curriculum > Virtual inquiry activities > Experience with variable manipulation and repetition. For secondary teachers, importance was ranked in the following order: Support for Concept Visualization = Virtual inquiry activities > Learner attention engagement > Alignment with curriculum = Experience with variable manipulation and repetition.

In the 'Contents structure of science simulation' category, elementary teachers prioritized Diverse manipulation of variables > Scientific accuracy of conceptual visualization > Realistic virtual activities > Design linked to textbook content > Learner autonomy in exploration > Appropriateness of inquiry process. For secondary school teachers, the order was different: Scientific accuracy of conceptual visualization > Realistic virtual activities > Diverse manipulation of variables > Design linked to textbook content > Learner autonomy in exploration > Appropriateness of inquiry process.

In the 'Functions of science simulation' category, elementary and secondary school teachers responded similarly, with familiarity with digital devices as the most important factor for both groups. Although some differences existed, the remaining factors were also prioritized in the same order as the overall responses. These results suggest that, regarding the digital functions of simulations, differences by school level are generally not prominent, and there is consensus that ease of use must be ensured, similar to the digital devices students typically use.

Table 5. The importance ratings for science simulation content in utilitarian importance

Measurement Category	Measurement Element	Total Answer M (SD)	Rank	Group EST M (SD)	Rank	SST M (SD)	Rank
Themes of Science Simulation	Alignment with curriculum	4.36(0 .65)	4	4.46(.588)	3	4.31(0.683)	4
	Support for concept visualization	4.51(0.67)	1*	4.54(.588)	1*	4.49(0.711)	1*
	Virtual inquiry activities	4.48(0.80)	2	4.46(.779)	4	4.49(0.820)	1*
	Experience with variable manipulation and repetition	4.34(0.71)	5	4.42(.584)	5	4.31(0.769)	4
	Learner attention engagement	4.43(0.72)	3	4.50(.659)	2	4.39(0.759)	3
Contents Structure of Science Simulation	Design linked to textbook content	4.29(0.75)	4	4.46(.588)	4	4.20(0.816)	4
	Scientific accuracy of conceptual visualization	4.50(0.71)	1 *	4.58(.717)	2	4.49(0.711)	1*
	Appropriateness of inquiry process	4.01(0.86)	6	4.29(.690)	6	3.88(0.904)	6
	Realistic virtual activities	4.37(0.79)	2	4.50(.659)	3	4.31(0.847)	2
	Diverse manipulation of variables	4.37(0.70)	2	4.63(.576)	1*	4.24(0.723)	3
	Learner autonomy in exploration	4.18(0.77)	5	4.42(.654)	5	4.06(0.801)	5
Functions of Science Simulation	User-friendliness of digital devices	4.47(0.69)	1*	4.63(.576)	1*	4.39(0.731)	1*
	Free three-dimensional manipulation	4.19(0.84)	2	4.29(.806)	3	4.14(0.866)	2
	Use of diverse multimedia	4.14(0.99)	3	4.46(.779)	2	3.98(1.051)	3
	Dialogic (interactive) feedback	3.92(1 .04)	4	4.29(.908)	3	3.73(1.056)	4
	Diverse types of assessment	3.74(1.11)	5	4.04(.955)	5	3.59(1.153)	5

*: 1 st Rank

Note. EST: elementary school teacher, SST: secondary school teacher

Analysis of the factors teachers perceived as important in utilizing science simulations revealed a notable difference in content composition. This indicates that differences in perception between elementary and secondary school teachers exist not only in the simulation development context but also in the utilization context. To determine whether these differences were statistically significant, an independent-samples t-test was performed using the response data from the elementary and secondary teacher groups (Table 6).

Table 6. The result of independent group t-test with utilitarian importance between groups

Measurement Category	Group EST *M*	EST *SD*	SST *M*	SST *SD*	*t*	*p*	Cohen's *d*
Themes of Science Simulation	4.48	0.42	4.40	0.55	0.616	0.540	0.163
Contents Structure of Science Simulation	4.48	0.38	4.20	0.59	2.438	0.017*	0.563
Functions of Science Simulation	4.34	0.66	3.97	0.77	2.037	0.045*	0.516

*: $p<0.05$

Note. EST: elementary school teacher, SST: secondary school teacher

The results of the independent samples t-test analysis for the three measurement categories revealed statistically significant differences in 'Contents structure of Science simulation' and 'Functions of science simulation', but not in 'Themes of science simulation'. Specifically, elementary school teachers perceived the importance of the content structure category higher than secondary school teachers. Regarding the importance of the functionality category, a significant difference emerged between the groups, with elementary school teachers rating it higher than secondary school teachers.

This indicates that, while there is no difference between elementary and secondary teachers in the subject matter they use when teaching science simulations, they hold different perceptions of their application in terms of content structure and functionality. Group comparisons were conducted for the sub-elements of the content structure and functional categories using independent-samples t-tests to determine which elements affected for the observed differences between elementary and secondary school teachers. Because no statistically significant difference was found in the thematic category, group comparisons were conducted for the sub-elements of the content structure and functional categories to determine which elements affected for the differences between elementary and secondary school teachers. An independent-samples t-test was conducted to determine whether there were significant differences in perceptions between elementary and secondary school teachers regarding the six sub-elements within the simulation's content structure categories that showed differences in the group comparison results (Table 7).

A survey on perceptions regarding the content composition categories for the importance of utilizing science simulation content revealed a statistically significant difference in perceptions between elementary school teachers and secondary school teachers concerning the 'diverse manipulation of variables' element. However, no significant differences in perception were found between the two groups regarding the following measurement elements: Design linked to textbook content, Appropriateness of inquiry process, Realistic virtual activities, Learner autonomy in exploration. In other words, elementary school teachers consider manipulating various variables to be an important factor when utilizing science simulations in their lessons, whereas secondary school teachers do not consider it important. These results, as seen in previous analyses, are related to the fact that secondary teachers place greater emphasis on the visualization of concepts and scientific validity. Also, it suggests that secondary teachers may not perceive simulations as tools for inquiry. This suggests the possibility that it may be perceived as a supplementary digital learning resource that aids students' understanding of concepts or inquiry-based learning, serving as an auxiliary means of learning.

Table 7. The result of independent group t-test with contents structure in utilitarian importance

Measurement Element	Group				*t*	*p*	Cohen's *d*
	EST		SST				
	M	*SD*	*M*	*SD*			
Design linked to textbook content	4.46	0.59	4.20	0.82	1.361	0.178	0.364
Scientific accuracy of conceptual visualization	4.58	0.72	4.49	0.71	0.527	0.600	0.126
Appropriateness of inquiry process	4.29	0.69	3.88	0.90	1.976	0.052	0.511
Realistic virtual activities	4.50	0.66	4.31	0.85	0.984	0.328	0.250
Diverse manipulation of variables	4.63	0.58	4.24	0.72	2.248	0.028*	0.597
Learner autonomy in exploration	4.42	0.65	4.06	0.80	1.885	0.063	0.275

*: p <0.05

Note. EST: elementary school teacher, SST: secondary school teacher

Next, an independent samples t-test was conducted to identify which of the five sub-elements within the functional category showed significant differences between elementary and secondary teachers who exhibited group differences (Table 8). Within the functional category, a significant difference in perception was found between groups for the interactive feedback element among the five sub-elements. Elementary school teachers perceived this element as more important than secondary school teachers did.

Table 8. The result of independent group t-test with contents function in utilitarian importance

Measurement Element	Group				t	p	Cohen's d
	EST		SST				
	M	SD	M	SD			
User-friendliness of digital devices	4.63	0.57	4.39	0.73	1.509	0.137	0.367
Free three-dimensional manipulation	4.29	0.81	4.14	0.87	0.705	0.483	0.178
Use of diverse multimedia	4.46	0.78	3.98	1.05	1.979	0.052	0.519
Dialogic (interactive) feedback	4.29	0.91	3.73	1.06	2.212	0.030*	0.567
Diverse types of assessment	4.04	0.96	3.59	1.15	1.652	0.103	0.425

*: p <0.05

Note. EST: elementary school teacher, SST: secondary school teacher

Teachers' Perceptions of the Intrinsic and Utilitarian Importance of Science Simulation

The items regarding the intrinsic importance to consider when developing science simulations and the utilitarian importance to consider when implementing them in lessons were designed to correspond to each other. Therefore, an IPA analysis was conducted to determine whether responses to these two types of importance were consistent or varied across contexts. The results of analyzing 73 elementary and secondary teachers as a single group are shown in Fig. 1. The cutoff points for distinguishing the domains were set at an average intrinsic importance score of 4.56 and an average utilitarian importance score of 4.27, following the IPA analysis method (Martilla & James, 1977). The overall response distribution showed a positive correlation. These results indicate that teachers tend to recognize elements they perceive as important intrinsic characteristics for developing science simulations as equally important when applying them to classroom instruction. In other words, practicing teachers recognize that simulations supporting science learning must effectively implement the characteristics they deem essential to be utilized in actual classroom settings.

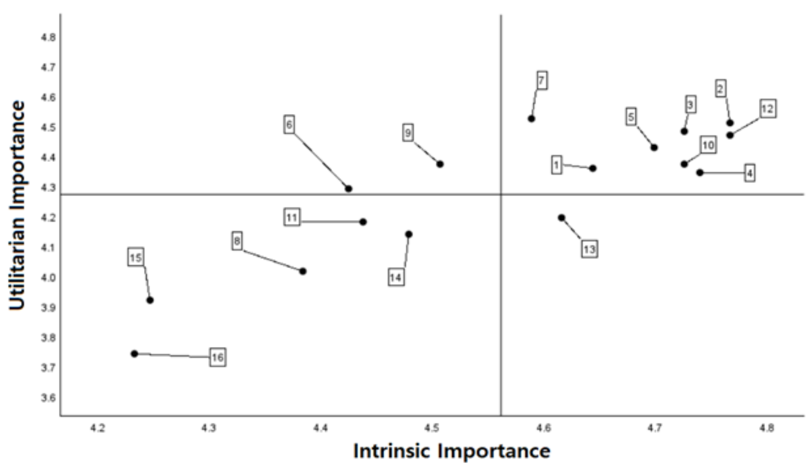

Fig. 1. The result of IPA about intrinsic & utilitarian importance
Note: Average line of intrinsic importance: 4.56, Average line of utilitarian importance: 4.27

In the traditional context of the conventional interpretation of Importance–Performance Analysis (IPA), the four quadrants can be broadly understood as areas for maintaining strengths, avoiding excessive investment, setting low priorities, and improving priorities. This study focused on simulation for science education; therefore, it needs to provide the terms for the elements in each quadrant in a pedagogical context. The first quadrant of the graph represents an area requiring continuous development, as it exhibits above-average intrinsic importance and utilitarian importance. Therefore, the elements included in this area can be considered core teaching and learning elements in the development and application of science simulations. The following elements were identified: Alignment with curriculum (#1), Support for concept visualization (#2), Virtual inquiry activities (#3), Experience with variable manipulation and repetition (#4), Learner attention engagement (#5), Scientific accuracy of conceptual visualization (#7), Diverse manipulation of variables (#10), and Familiarity with digital devices (#12). Particularly, the Scientific accuracy of conceptual visualization (#7) element showed the highest utilitarian importance, while the Support for concept visualization (#2) and User-friendliness of digital devices (#12) elements ranked highly in both intrinsic importance and utilitarian importance. These results indicate that these items are key factors determining the quality of science simulations and are also essential attributes required in actual educational settings. Therefore, in the development and improvement of science simulations, a strategy that focuses on and improves these elements should be prioritized.

The secondary quadrant represents areas with below-average intrinsic importance and high utilitarian importance, indicating elements for which excessive investment or further improvement should be restrained. Therefore, elements included in this area can be considered selective elements for classroom application in the development and implementation of science simulations. Design linked to textbook content (#6) and realistic virtual activities (#9) were positioned. Although teachers rated these elements relatively low as intrinsic attributes of the content, they correspond to elements that are considered important in actual classroom practice. Therefore, from the perspective of teachers—the primary users of digital learning materials in the classroom—it means that science simulations can be actively utilized in teaching when they are linked to textbooks and support realistic virtual activities.

The third quadrant represents areas with both intrinsic importance and utilitarian importance below average, corresponding to low-priority domains. The importance of elements within this area may vary depending on users' perspectives for development and application of scientific simulations, so they can be considered user-context elements. Because it might reflect the development of simulation according to teachers' or experts' demands. Appropriateness of inquiry process (#8), Learner autonomy in exploration (#11), Use of diverse multimedia (#14), Dialogic (interactive) feedback (#15), and Diverse types of assessment (#16) were positioned in the lower-importance quadrant. Notably, Diverse types of assessment (#16) recorded the lowest scores in both importance indicators. Learner autonomy in exploration (#11) and Use of diverse multimedia (#14) fall within the third quadrant. However, their utilitarian importance scores are close to the average (4.27), indicating they may be elements worth considering for potential implementation. Elements located in this area may be interpreted as having relatively lower priority compared to those in the first and second quadrants, and thus should be considered lower in resource allocation during simulation development. However, elements such as suitability for the inquiry process—a crucial learning method in science education—learner autonomy, and interactive feedback for engagement are educationally meaningful factors in science teaching and learning. Nevertheless, the perceived low importance of these elements can be attributed to relative differences in perception. That is, in terms of the intrinsic importance of digital-based simulations, aspects such as curriculum linkage, visualization, and realism are expected to be relatively more important than inquiry-process suitability, which is highly valued in traditional science activities. However, deeper analysis is required regarding the low recognition of inquiry process suitability and learner autonomy in areas like interactive feedback, which signifies two-way interaction, and usability.

The fourth quadrant, with high intrinsic importance but low utilitarian importance, represents an area requiring priority improvement through proactive management. Therefore, the elements included in this quadrant can be considered primary improvement elements in the development and application of science simulations. Free three-dimensional manipulation (#13) was included. While field teachers recognize this element as important for simulation development, it implies that its importance is relatively low in actual classroom situations. That is, this function or attribute has a low priority for classroom use, but it remains an element to be considered from a development perspective. Teachers generally consistently recognized the intrinsic and practical importance of science simulations. However, Design linked to textbook content, Realistic virtual activities, and Free three-dimensional manipulation were identified as areas where a discrepancy exists between perceived intrinsic and practical importance. Therefore, effective science simulation development requires a differentiated strategy that prioritizes core teaching and learning elements, complements optional classroom applications, and efficiently adjusts development-focused elements. However, for user-centered elements, the priority for consideration should vary based on teachers' or students' actual needs and usage purposes.

Previous studies have shown statistically significant differences in the perceived importance of science simulations between elementary and secondary school teachers. Therefore, it is necessary to confirm whether such differences exist between groups in the IPA analysis. To this end, the results of analyzing teachers' perceptions of the intrinsic importance and utilitarian importance of science simulations, based on the response results calculated for each group, are presented in Fig. 2.

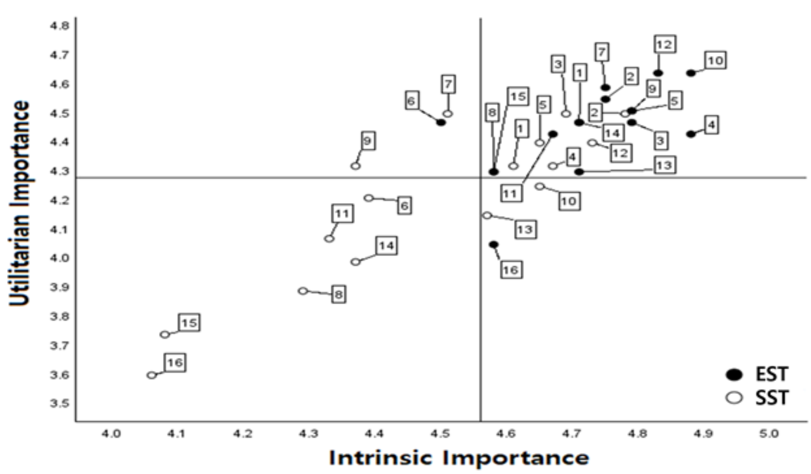

Fig. 2. Comparison of IPA results between elementary and secondary teachers
Note: Average line of intrinsic importance: 4.56, Average line of utilitarian importance: 4.27
EST: elementary school teacher, SST: secondary school teacher

Looking at the overall distribution of results, both groups tended to perceive greater practical value in classroom use, as they rated simulations' intrinsic value higher. However, there were distinct differences between the groups. Elementary teachers' responses were primarily distributed in the upper right quadrant of the graph, indicating a tendency to rate overall importance and practical utility highly. In contrast, secondary teachers' responses showed specific elements in the upper right quadrant, while a significant number were in the lower left quadrant. These results indicate that secondary teachers evaluate the educational importance and practical applicability of science inquiry simulations lower than elementary teachers do, and that the areas of perception differ significantly between the groups.

The following elements were commonly located in the same quadrant: Alignment with curriculum (#1), Support for concept visualization (#2), Virtual inquiry activities (#3), Experience with variable manipulation and repetition (#4), Learner attention engagement (#5), and User-friendliness of digital devices (#12). This indicates that these measurement elements are recognized as the most critical and should be prioritized when developing and utilizing science inquiry simulations.

In the area of teaching application selection factors, where intrinsic importance is below average but utilitarian importance is high, elementary school teachers ranked the Design element linked to textbook content (#6) as most important. Elementary school teachers recognize the importance of textbook linkage in terms of utilization, but rate its importance lower in terms of development. In contrast, secondary school teachers recognize scientific validity and realism as important factors in terms of utilization, but do not perceive them as major considerations in terms of development.

In the area of user-context factors, where both intrinsic and utilitarian importance were below average, no such elements existed among elementary school teachers (EST). For secondary school teachers (SST), the elements Design linked to textbook content (#6), Appropriateness of inquiry process (#8), Learner autonomy in exploration (#11), Use of diverse multimedia (#14), Dialogic (interactive) feedback (#15), and Diverse types of assessment (#16) were positioned. The fact that secondary teachers rated the elements Appropriateness of inquiry process (#8), Dialogic (interactive) feedback (#15), and Diverse types of assessment (#16) as low indicates that they do not perceive simulation content as significantly important—both for its intrinsic value and for practical classroom application—in terms of providing logical inquiry procedures or the system's inherent interactive engagement and assessment functions. This result can be attributed to the perception of digital simulations as 'supportive instructional tools for teachers' instructional design, rather than as core 'process-oriented tools' driving the entire learning process. Ultimately, teachers desire simulations to be intuitive, auxiliary-level tools that can be flexibly utilized as needed in lesson delivery, rather than tools that complexly replace the entire inquiry process, even when implementing science inquiry activities.

In contrast, the development-focused element areas with high intrinsic importance but low utilitarian importance included the Diverse types of assessment (#16) element for elementary teachers and the Diverse manipulation of variables (#10) and Free three-dimensional manipulation (#13) elements for secondary teachers.

Analysis of the alignment between the intrinsic importance of science simulation development and its utilitarian importance in classroom settings, along with the perceptions of elementary and secondary teachers, revealed both common characteristics and distinct differences between the groups. First, both elementary and secondary teachers generally held consistent opinions regarding the importance of simulations. While some elements showed inconsistencies between intrinsic and utilitarian importance, they demonstrated overall consistent perceptions. Ultimately, teachers exhibit a specific cognitive pattern regarding simulations, which can be interpreted as informing their decisionmaking about their use. Therefore, when developing science simulations, elements that teachers in the field perceive as important must be core components. Only when these elements are implemented can practical field applicability be expected. Furthermore, the distinct perceptual differences between elementary and secondary school teacher groups suggest that developing simulations with a single type, structure, or function may positively impact one group but negatively impact the other in terms of development feasibility. In other words, simulations developed to support science learning should be designed with enhanced structures and functions appropriate for each school level, rather than being developed with a single uniform structure and form.

Discussions

The findings that ‘Support for concept visualization’ and ‘User-friendliness of digital devices’ were rated highly by both elementary and secondary school teachers indicate that even if science simulations incorporate diverse functions and content, their practical use as educational tools is unlikely without visualization tailored to learners' levels and a user-friendly design. This finding aligns with prior research (Byeon, 2024), which identified ‘low usability’ as the primary reason for low adoption rates of intelligent science lab platforms. Consequently, when developing science simulation content, the quality and convenience of the materials must be guaranteed.

The elementary science curriculum tends to emphasize sparking learners' interest in natural phenomena and accumulating phenomenological experiences according to their level (MOE, 2022). Therefore, elementary teachers can actively use manipulative activities in science simulations as scaffolding to enhance students' access to inquiry activities. In contrast, the secondary science curriculum emphasizes rigorous processes for logically inferring causal relationships between variables and controlling errors (MOE, 2022). However, secondary teachers' perceptions suggest that current simulation learning materials suffer from inadequate implementation of inquiry processes and a lack of realism. This may explain why they rated the importance of using these materials in actual classes low in the survey. Alternatively, it could stem from a lack of knowledge about how to appropriately integrate digital inquiry tools into lessons (Kwak et al., 2025).

Additionally, secondary school teachers perceived ‘Scientific accuracy of conceptual visualization’ as the most important category in content organization. Among the secondary teachers participating in this study, high school teachers accounted for 75.51%. Given the high school science curriculum's requirement for qualitative and quantitative confirmation of scientific concepts and the learning characteristics of high school students, it can be interpreted that they judged ‘accuracy’—free from scientific errors—as the most important condition for classroom use, rather than interest or realism. This difference in perception between elementary and secondary teachers suggests that the criteria for utilizing simulations in science education have shifted from student-led ‘inquiry activities (Doing Science)’ to the ‘visual explanation (Viewing Science)’ of abstract concepts. That is, while elementary teachers perceive science simulations as a primary learning resource that can replace inquiry activities or be actively utilized in subject lessons, secondary teachers tend to limit their use to supplementary learning materials that aid understanding of complex concepts and prevent misconceptions.

Conversely, both elementary and secondary school teachers rated various types of assessment and interactive feedback as relatively low in importance. This result suggests that, in current classroom contexts, teachers tend to perceive science simulations primarily as supportive instructional tools rather than as systems responsible for diagnosing learning processes or providing formative feedback. However, assessment and feedback functions are increasingly recognized as essential for providing personalized learning support in emerging learning environments supported by artificial intelligence systems and big data. From this perspective, the relatively low importance ratings observed in this study should not be interpreted as indicating limited educational value, but rather as reflecting teachers' current usage contexts and perceptions of science simulations. Accordingly, these findings suggest that assessment and feedback functions warrant consideration as future design elements as digital learning systems continue to evolve.

Conclusions & Implications

This study analyzed perceptions of science inquiry simulation content across three measurement categories—theme, content structure, and function—among elementary teachers, secondary teachers, and expert groups. By examining the consistency between intrinsic importance and practical importance, the following conclusions were drawn.

First, perceptions of the intrinsic importance of science inquiry simulations partially aligned between science education experts and practicing teachers, though differences existed. The expert group recognized Alignment with curriculum, Virtual inquiry activities, and Support for concept visualization as key elements within the subject domain. However, secondary teachers prioritized Support for concept visualization, whereas elementary teachers rated Experience with variable manipulation and repeated trials as the most important element in the themes domain. This difference suggests that experts view the intrinsic importance of simulations from an ideal learning perspective, while classroom teachers perceive importance based on practical needs. That is, elementary teachers focus on activity-centered educational activities, while secondary teachers focus on concept-centered educational activities, leading to differing perceptions of simulation importance. Conversely, regarding content and functionality, they commonly recognized 'Diverse manipulation of variables' and 'User-friendliness of digital devices' as the most core values. A consensus emerged among educational stakeholders on the essential conditions: science simulations must allow for diverse manipulation of variables, akin to or exceeding actual inquiry activities, and must be easily accessible to everyone.

Second, while elementary and secondary teachers share some common perceptions about the importance of considering utilization factors when applying science inquiry simulations to lessons, numerous elements reveal differing levels of recognition. Regarding simulation themes and functional areas, both elementary and secondary teachers recognized concept visualization and familiarity with digital devices as important factors. However, in terms of content, elementary teachers prioritized manipulating various variables, while secondary teachers emphasized conceptual visualization. This difference likely arises because elementary teachers focus on activity-centered instruction, central to elementary science education, while secondary teachers emphasize concept-centered instruction.

Third, there were elements that should be prioritized during the development of science simulations, as well as those that should be considered based on users' needs. According to results from the importance analysis, the intrinsic and utilitarian importance of science simulations among field teachers generally showed a consistent trend. The elements that should be considered at a high level were derived as: Alignment with curriculum, Support for concept visualization, Virtual inquiry activities, Learner attention engagement, Diverse manipulation of variables, and User-friendliness of digital devices. However, significant differences in perception were observed between elementary and secondary school teachers. Unlike elementary teachers, secondary teachers perceived Design linked to textbook content, Learner autonomy in exploration, Free three-dimensional manipulation, Use of diverse multimedia, and Diverse types of assessment as less important. These group differences indicate that teachers' needs and expectations vary by school level. Furthermore, when the focus of science instruction in the field differs, it becomes difficult to apply the same structure or framework to the available digital simulations.

This study confirmed that factors must be considered when developing science simulations and that teachers' perceptions differ across school levels. Based on the findings of this study, the following recommendations are proposed.

First, it is necessary to distinguish between the primary factors to consider in developing science simulations and user-customized elements, and to establish a user-centered development direction. While science education experts and classroom teachers shared common perceptions of important factors in simulation development, differing perspectives also existed. Elementary and secondary teachers even differed in their focus—activity-centered instruction versus concept-centered instruction—depending on the instructional context and learner characteristics. Their perceived importance levels also varied across functional aspects. Therefore, it is necessary to shift from developer-centered development—which uniformly standardizes simulation structure, process, and elements for convenience—to user-centered development that aligns with the needs and requirements of actual users: classroom teachers and learners.

Second, there is a need for teacher re-education programs that align with the direction and philosophy of digital-based science inquiry, alongside teacher training programs that effectively utilize digital tools and learning materials, including science simulations, for in-service teachers. The fact that elements crucial in digital-based science learning—such as suitability for the inquiry process, interactive feedback, and diversity in assessment—scored low despite recognition of simulation's importance indicates that the purpose and direction of using digital learning materials are perceived as separate from the inquiry process. In other words, while teacher education programs focused on practical, hands-on application may contribute to the short-term spread of digital tools, they can also have the adverse effect of diminishing the experience of scientific thinking and problem-solving processes, which are the essence of the science curriculum. In this context, it may be necessary to review and redefine the direction of teacher education programs concerning digital-based teaching and learning methods.

Conflicts of Interest

The authors declared no conflicts of interest.

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