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Original Paper

User Behavior toward Multimodal Digital Publishing for Science and Innovation Education from the Perspective of Knowledge Services: An Empirical Analysis Based on the Technology Acceptance Model

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Abstract

The continuous advancement of the national digital education strategy and the rapid development of science and technology education have put forward higher requirements for the quality of educational resources supply and knowledge service capabilities. Multimodal digital publishing has become a key breakthrough in this context. Focusing on the dimension of knowledge service, this study comprehensively uses literature review and questionnaire survey to investigate the use behavior and influence mechanism of middle school students on multi-modal digital publishing products of science and innovation education. The data show that the overall attitude of students is positive, and perceived usefulness, ease of use and pleasure all significantly affect the attitude of use. Among them, perceived usefulness has the strongest explanatory power, and attitude is positively transmitted to behavioral intention. At the same time, the current system still has deficiencies in knowledge organization, learning assistance, technology integration and service architecture. In this regard, this paper proposes an optimization scheme covering multimodal resource reorganization, full intervention in the learning process, deep coordination of technical tools and educational goals, and construction of a long-term service mechanism, in order to provide a reference for product iteration and service efficiency improvement.

Keywords

knowledge services, science and innovation education, multimodal digital publishing, technology

acceptance model (TAM), secondary school students

1. Introduction

The digital transformation of China's publishing industry originated from the penetration of electronic information technology in the 1990s, and has continued to advance along the track of digitization, networking and intelligence. According to the "Annual Report of China's Digital Publishing Industry 2024-2025", the total revenue of the industry in 2024 has reached 1748.536 billion yuan, an increase of 8.07% year-on-year. With the comprehensive penetration of artificial intelligence, big data, virtual reality and other technical communities into all aspects of content production, editing and knowledge distribution, multimodal product forms such as e-books, audiobooks, interactive publications and even virtual laboratories have emerged. The mode of knowledge dissemination has shifted from the traditional one-way output of text to the compound pattern of text, image, audio, video and interactive experience.

If the vision is expanded to a more macro industrial and social background, it is not difficult to find that the above-mentioned technological changes form a historical intersection with the new round of scientific and technological revolution and industrial transformation. The continuous breakthroughs in frontier fields such as artificial intelligence, quantum information and biotechnology have made the cultivation of scientific and technological innovative talents an urgent issue at the national strategic level. In this context, the "Outline of the National Action Plan for Scientific Literacy (2021-2035)" (State Council, 2021) and the "Opinions on Strengthening Science and Technology Education in Primary and Secondary Schools (2025)" (Ministry of Education, 2025) have been issued one after another. From the dimensions of curriculum system design, teaching method reform, teacher capacity building and education resource supply, science and technology education has been systematically deployed. The interdisciplinary nature, inquiry practicality and innovation orientation of science and innovation education itself also put forward higher requirements than traditional education for the advancement, situational realism and accessibility of teaching resources.

In contrast, on the current supply side, the traditional educational publishing resources based on static texts have become increasingly difficult to respond to the realistic demands of science and innovation education. The structural contradictions exposed on the supply side of resources are worthy of vigilance: first, a considerable number of digital publishing products only stay in the electronic reproduction of paper teaching materials or shallow science popularization, and there is a lack of organic integration between various multimodal elements; second, there is a clear disconnect between resource development and actual teaching scenarios and learning processes, and a dynamic and learner-centered knowledge service system has not yet been truly established. What is more noteworthy is that some products have fallen into the misunderstanding of "emphasizing technical display and neglecting cognitive service" in practical application, and have insufficient support for the continuous

growth of learners. As far as the research level is concerned, most of the existing work focuses on the evaluation of digital resource construction and educational application effects, while the specialized and systematic exploration of user behavior patterns and their formation mechanisms is still weak.

Therefore, from the perspective of knowledge services, this study introduces the Technology Acceptance Model (TAM) and employs questionnaire surveys to investigate the factors influencing users' adoption behaviors of multimodal digital publishing products for science and technology innovation education. Based on the findings, this study proposes optimization strategies to provide references for the digital transformation of educational publishing and the enhancement of knowledge service capabilities.

2. Theoretical Foundations and Literature Review

2.1 Theoretical Foundations

2.1.1 Multimedia Learning Theory

Richard E. Mayer defined "multimedia" in his multimedia learning theory: it does not refer to the simple superposition of multiple media, but refers to the coexistence and coordination of two kinds of information representation methods: text and picture. Among them, the written materials can be resorted to both written symbols and oral narratives; the picture material covers a variety of visual forms such as graphics, lines, dynamic images and videos. Learners need to deal with these two types of information at the same time, construct corresponding psychological representations respectively, and use cognitive processing activities to make the two interrelated, and finally reach an understanding of the content, which is the basic mechanism of multimedia learning (Sheng & Zhuang, 2013).

The above process is not a passive information reception, but an active cognitive construction process: learners need to select and organize the input information and integrate it with the existing knowledge system to achieve deep understanding and effective transfer. As far as the specific context of this study is concerned, this theory provides an explanatory cognitive perspective - it helps to clarify how multimodal content can promote learners' knowledge processing, and at the same time puts forward constraints for the design level: multimodal presentation should not blindly pursue sensory richness, but should implement structured information organization based on the goal orientation of learning tasks, so that learners' cognitive resources can be guided in a targeted manner.

2.1.2 Constructivist Learning Theory

Constructivist learning theory originated in the academic context of cognitive psychology in the 20th century. After decades of development, it has grown into an important theoretical pillar with paradigmatic significance in the field of learning science. The core concern of this theory lies in the confirmation of learners' subjectivity: knowledge is not transmitted as a ready-made thing from the outside, but is actively grown by individuals based on their existing experience in continuous interaction with the situation in which they are located (Gao, 2025) .

Introducing this theoretical perspective into this study can provide an explanatory framework for examining the learning function of multimodal digital publishing products. At the level of symbol supply, the collaborative presentation of multimodal resources such as text, image, audio and video constitutes a multi-dimensional cognitive stimulation field, which helps to activate the existing experience schema in the learner's mind and create favorable conditions for the initiation and deepening of the meaning construction process. From the perspective of service concept, the characteristics of user centralization, situational adaptation and personalized push advocated by knowledge service exactly echo the constructivism's "active construction mechanism" and "situational dependence".

2.1.3 Technology Acceptance Model Theory

Fred D. Davis, an American scholar, introduced several new explanatory variables on the basis of rational behavior theory in 1989, which formed the Technology Acceptance Model (TAM). The original intention of this model is to explain and predict users' adoption behavior of computer systems more accurately, so as to provide a theoretical tool for the effective implementation of information technology in the improvement of organizational effectiveness.

As far as the core proposition of the model is concerned, the user's system use behavior does not occur directly, but is driven by a chain of psychological paths: behavioral intention constitutes a direct antecedent of actual use, and this intention is also affected by both use attitude and perceived usefulness. Further, the use attitude itself is shaped by perceived usefulness and perceived ease of use. It is worth noting that external variables do not directly affect attitudes or behavioral intentions, but indirectly exert influence through perceived usefulness and perceived ease of use as intermediary channels, and ultimately transmit to the actual use behavior level (Davis et al., 1989).

In terms of the specific context of this study, the core connotation of perceived usefulness can be summarized as: whether middle school students recognize that digital publishing products or platforms can effectively improve their learning efficiency, optimize academic achievements or improve the quality of knowledge acquisition in the context of science and innovation education. In other words, to what extent multimodal resources can serve the depth of understanding, application flexibility and innovation ability required by science and innovation education. In contrast, perceived ease of use is concerned with another dimension: the operational convenience that middle school students feel when using the above platforms or resources, specifically related to the intuitive degree of content acquisition, the fluency of interactive feedback, and the clarity and identifiability of learning paths. It is worth noting that under the premise of maintaining the same conditions, the difficulty of system operation often constitutes one of the decisive factors for users' acceptance and continuous use of related digital publishing services - the higher the ease of use, the greater the possibility of continuous use.

2.2 Literature Review

2.2.1 Research on Knowledge Services in Digital Publishing

The existing research on knowledge services of digital publishing can be summarized into three directions: service mode, development challenges and technology empowerment. In terms of service mode, Guo et al. (2023) extracted five modes of knowledge resource library, terminal equipment service, social media sharing, open collaborative creation and paid subscription, which together constitute the hierarchical operation framework of the industry. Focusing on specific areas, Jin Yu (2024) points out that children's publishing is forming a service system around the educational scene, integrating audiobooks, digital reading and "reading + education". At the level of development challenges, Li Lingfei (2024) observed that small and medium-sized publishers lack the ability to embed intelligent technology, resulting in a shortage of personalized knowledge products and limited service scenarios; Su Yuqi (2024) pointed out that the industry's income relies too much on content sales and subscriptions, and the development of value-added services and platform-based operations lags behind.

2.2.2 Research on Digital Publishing for Science and Innovation Education

The research on digital publishing for science and innovation education focuses on three aspects: digital resource development, curriculum integration and technology application. At the level of resource development, Yang (2016) pointed out that traditional popular science publications have a long cycle and limited interaction, and digital publishing has become the direction of transformation by virtue of cross-media and interactive advantages. Xiang Peng (2017) advocates that science communication products should take a professional and refined path, and integrate video, games and virtual reality to enhance the experience. In terms of curriculum integration, Bie Huaiwei (2019) proposed to integrate the STEAM concept into science and innovation teaching materials, and strengthen the cultivation of interdisciplinary and innovative ability; based on the experience of Guangdong Education Publishing House (2024) proposed that teaching materials, digital resources, network platforms and after-school services should be developed in a coordinated manner to build a complete science education resource system.

2.2.3 Research on Multimodal Digital Publishing

Multimodal digital publishing research mainly covers three dimensions: technology development, communication mechanism and application scenarios. At the technical level, AI, VR, AIGC and big language models are promoting multimodal publishing from audio-visual integration to intelligent and immersive experience. Wu Weihua et al. (2023) pointed out that publishing is evolving from audio-visual communication to a multi-sensory system, and VR technology blurs the boundary between virtual and physical worlds. Wan Anlun et al. (2019) divided the publishing evolution into three stages: hard copy, soft copy and virtual publishing, and believed that AI and consciousness-oriented publishing were reshaping the future reading scene. In terms of communication mechanism, multimodal fusion

reconstructs the organization and dissemination of information. Zhou Rongting et al. (2023) predicted that digital publishing will develop into a cross-media, cross-platform and cross-scene integrated communication ecology. Zhao Yan et al. (2020) found that digital publishing research increasingly focuses on knowledge service, intellectual property value and user orientation. Wang Xun (2025) emphasized that the essence of multimodal publishing lies in the deep integration of content production, technology platform and user interaction. In terms of application scenarios, multimodal digital publishing is widely used in science communication and children's reading. Feng Lijun et al. (2026) proposed that generative AI can transform popular science content into short video and audio, and promote knowledge from static storage to dynamic dissemination.

3. Research Design

3.1 Model Development

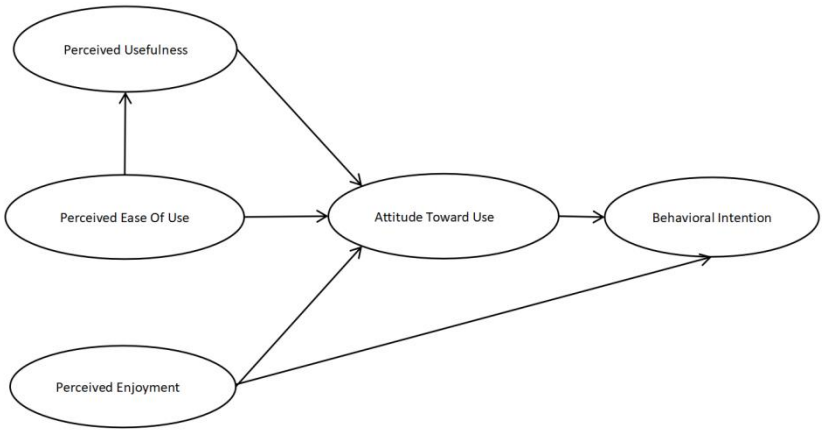

Figure 1. Theoretical Research Model

The Technology Acceptance Model (TAM) has shown strong situational adaptability and explanatory power through the adjustment of variables in different research situations. For example, Han van der Heijden (2003) incorporated perceived enjoyment into the TAM framework to explain users' willingness to use the website. On the basis of retaining the core constructs "perceived usefulness" and "perceived ease of use" of TAM, this study introduces "perceived enjoyment" as an extended variable to examine learners' behavioral intention and its influencing factors for multimodal digital publishing products of science and innovation education. The extended expectation model can more effectively explain users' acceptance behavior of multimodal digital publishing products in the context of science and technology innovation education.

3.2 Variable Definitions and Research Hypotheses

3.2.1 Perceived Enjoyment

Venkatesh and Bala (2008) introduced perceived enjoyment into the Technology Acceptance Model (TAM), and defined it as the degree of pleasure and psychological satisfaction experienced by users when using technology products, representing an intrinsic motivation derived from the use process itself. The digital products of science and technology education integrate digital technology and educational content, with diversified resources, interactive functions, and immersive experiences. The content design and presentation of digital products of science and technology education are helpful to stimulate learners' interest and enhance their participation. Based on this, this study incorporates perceived enjoyment into the model as an important factor affecting the intention to use - when learners feel pleasure in using, it is easier to recognize the educational value of the product and form a positive attitude towards use. Accordingly, the following hypotheses are proposed:

H1: Perceived enjoyment positively affects learners' attitudes toward using science and technology education digital products.

H2: Perceived enjoyment positively affects learners' behavioral intention to use science and technology education digital products.

H3: Use attitude mediates the positive relationship between perceived enjoyment and learners' behavioral intention.

3.2.2 Perceived Usefulness

TAM defines perceived usefulness as the degree to which individuals believe that the use of a technology can improve their learning or work performance. In this study, the construct specifically points to learners' subjective evaluation of digital products of science and technology education in improving learning effect, improving learning efficiency and promoting knowledge acquisition. Perceived usefulness is widely regarded as one of the key factors affecting users' attitudes and behavioral intentions. Once learners think that the product has practical value for learning, it is easier to form a positive evaluation and enhance the willingness to continue to use. Accordingly, the following assumptions are made:

H4: Perceived usefulness positively affects learners' attitudes toward using science and technology education digital products.

H5: Use attitude mediates the positive relationship between perceived usefulness and learners' behavioral intention.

3.2.3 Perceived Ease of Use

TAM defines perceived usefulness as the degree to which individuals believe that the use of a technology can improve their learning or work performance. In this study, the construct specifically points to learners' subjective evaluation of digital products of science and technology education in improving learning effect, improving learning efficiency and promoting knowledge acquisition.

Perceived usefulness is widely regarded as one of the key factors affecting users' attitudes and behavioral intentions. Once learners think that the product has practical value for learning, it is easier to form a positive evaluation and enhance the willingness to continue to use.

Accordingly, the following assumptions are made:

H6: Perceived ease of use positively affects perceived usefulness of science and technology education digital products.

H7: Perceived ease of use positively affects learners' attitudes toward using science and technology education digital products.

H8: Use attitude mediates the positive relationship between perceived ease of use and learners' behavioral intention.

3.2.4 Use Attitude and Behavioral Intention

Philip Kotler defined attitude as an individual's psychological evaluation and behavioral tendency toward an object (Brown et al., 1994). In TAM, "use attitude" refers to users' overall positive or negative evaluation of using a particular technology (Davis et al., 1989). In this study, use attitude represents learners' overall evaluation and emotional disposition toward science and technology education digital products.

"Behavioral intention" refers to learners' subjective willingness to continue using science and technology education digital products for learning, exploration, and knowledge acquisition after experiencing and evaluating them. According to TAM, use attitude is a key antecedent of behavioral intention, and a more positive attitude is expected to strengthen users' intention to continue using the product.

Therefore, the following hypothesis is proposed:

H9: Use attitude positively affects learners' behavioral intention to use science and technology education digital products.

3.3 Sources of Measurement Items

The questionnaire used in this study consists of two sections. The first section collects respondents' demographic information, including gender, age, educational level, school stage, and region. It also investigates learners' experiences in science and technology education, use of electronic devices, frequency and duration of using science and technology education digital products, product types used, and experience with AI tools.

The second section measures learners' use of multimodal digital publishing products for science and technology education at the K–12 level. The constructs include "perceived enjoyment", "perceived usefulness", "perceived ease of use", "use attitude", and "behavioral intention".

All measurement items were assessed using a "five-point Likert scale", where "1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree".

Table 1. Measurement Items and Sources of Variables

Research Variable	Measurement Item	References
PE	PE1. I find the content of multimodal digital products for science and innovation education intere sting. PE2. Using multimodal digital products for science and innovation education provides me with an enjoyable learning experience. PE3. I think using multimodal digital products for science and innovation education can stimulate my curiosity. PE4. I am satisfied with the usage process and experience of multimodal digital products for science and innovation education.	Moon & Kim (2009) Yanqing Ma (2014)
PU	PU1. Using multimodal digital products for science and innovation education can improve my learning outcomes in science and technology-related subjects. PU2. Using multimodal digital products for science and innovation education helps me better understand relevant knowledge. PU3. Using multimodal digital products for science and innovation education can increase my interest in science and innovation learning. PU4. Using multimodal digital products for science and innovation education helps me gain a deeper understanding of complex scientific concepts.	Davis (1989)
PEOU	PEOU1. I can easily obtain the learning resources I need through multimodal digital products for science and innovation education. PEOU2. I do not need to spend too much effort learning how to operate multimodal digital products for science and innovation education. PEOU3. The content categories of multimodal digital products for science and innovation education are clear, allowing me to quickly find the learning resources I need.	Davis (1989) Shin (2007) Pedersen (2005)

	PEOU4. The interface design of multimodal digital products for science and innovation education is use r-friendly, and the operation process is easy to unde rstand.	
	PEOU5. Overall, I think using multimodal digital products for science and innovation education is not difficult.	
ATU	ATU1. I enjoy using multimodal digital products for science and innovation education.	Venkatesh&Davis (2000)
	ATU2. I think using multimodal digital products for science and innovation education is a good idea.	Moon & Kim (2009) Vijayasarathy (2004)
	ATU3. I think using these products for science and innovation learning is worthwhile.	
	ATU4. Overall, I recognize the value of multimodal digital products for science and innovation education in supporting my learning.	
BI	BI1. In the future, I will continue using multimodal digital products for science and innovation education rather than stop using them.	Venkatesh & Davis (2001) Moon & Kim (2009) Ziyu Luo (2025)
	BI2. I am willing to give priority to multimodal digital products for science and innovation education when obtaining learning resources in the future.	
	BI3. I am willing to continue following new content and functions released by multimodal digital products for science and innovation education.	
	BI4. If appropriate opportunities arise, I will recommendmultimodal digital products for science and innovation education to my classmates or friends.	

3.3 Questionnaire Distribution

To ensure the reliability and accuracy of the questionnaire items, a pilot survey was conducted before the formal questionnaire distribution. Based on the results of the pilot survey, the reliability and validity analyses met the required standards. The questionnaire was further revised and refined according to the feedback and analysis results from the preliminary survey, which provided the

foundation for the large-scale questionnaire distribution.

The main participants of this study were users who had experience with multimodal digital products for science and innovation education. A convenience sampling method was adopted, and the questionnaire was distributed online to invite participants with diverse demographic characteristics to complete the survey.

A total of 330 questionnaires were distributed, of which 320 questionnaires were returned. After data screening, 302 valid questionnaires were obtained, resulting in an effective response rate of 91.5%. Among the valid respondents, 149 were male participants and 153 were female participants.

4. Empirical Results and Discussion

4.1 Descriptive Statistics

4.1.1 Basic Characteristics of Respondents

From the perspective of age distribution, more than half of the respondents were aged 15-17 years old, and high school students (54.97%) were slightly more than junior high school students (45.03%). In terms of gender, there were 149 males (49.34%) and 153 females (50.66%), with a basically balanced distribution. In terms of school types, public school students account for 84.11%, which is basically consistent with the composition of China's basic education system. In terms of geographical distribution, more than 60% (36.42% + 24.83%) of respondents in third-tier cities and counties/townships, 28.15% and 10.6% in second-tier and first-tier cities, respectively.

Table 2. Demographic Characteristics of Respondents

Variable	Category	Number (N)	Percentage （%）
Age			
	12-14	94	31.13%
	15-17	171	56.62%
	18-19	37	12.25%
	Total	302	100%
Gender			
	Male	149	49.34%
	Female	153	50.66%
	Total	302	100%
Educational Stage			
	Junior high school	136	45.03%
	Senior high school	166	54.97%
	Total	302	100%

School Type			
	Public school	254	84.11%
	Private school	48	15.89%
	Total	302	100%
Region			
	First-tier city	32	10.6%
	Second-tier city	85	28.15%
	Third-tier or lower-tier city	110	36.42%
	County/township	75	24.83%
	Total	302	100%
Whether Having Science and Innovation Learning Experience			
	Yes	169	55.96%
	No	133	44.04%
	Total	302	100%
Average Weekly Time Spent Using Electronic Devices for Learning			
	Less than 1 hour	54	17.88%
	1-3 hours	127	42.05%
	3-8 hours	94	31.13%
	More than 8 hours	27	8.94%
	Total	302	100%

4.1.2 Characteristics of Usage Behavior

To analyze the usage behavior characteristics of participants regarding multimodal digital products for science and innovation education, this study conducted descriptive statistical analysis on the following questionnaire items: “6. Have you ever participated in science and innovation-related learning activities (such as programming, science experiments, STEAM courses, etc.)?”, “7. On average, how much time do you spend using electronic devices (mobile phones/computers/tablets) for learning each week?”, “8. How frequently do you use digital products for science and innovation education each week?”, “9. How long have you been using this type of digital learning product?”, “11. Have you used AI-assisted learning tools?”, and “12. Have you ever used paid digital learning products for science and innovation education?”. The descriptive statistical results are presented in Table 3. Regarding science and innovation learning experience, 55.96% of respondents reported having participated in relevant learning activities, indicating that science and innovation education has achieved a certain level of

popularity among K–12 students. However, nearly 40% of students still lack related experience, representing a potential user group for future development. In terms of usage habits, 42.05% of students spend 1-3 hours a week on digital devices for learning, and 31.13% spend 3-8 hours, indicating that digital learning is gradually integrating into daily practice, but more than 8 hours a week is still a minority. The frequency of use of digital products in science and technology innovation education is mainly in the middle and low frequency : 44.04% of them use 1 ~ 2 times a week, 26.49% of them use more than 3 times, which shows that some students have strong participation. In terms of the duration of use, 57.61% of respondents had more than 6 months of experience, of which 1 ~ 2 years accounted for the largest proportion (29.8%), and 21.85% had more than 2 years, indicating that the digital products of science and technology education have a certain attraction to users.

Table 3. Characteristics of Usage Behavior

Variable	Category	Number (N)	Percentage (%)
Whether Having Science and Innovation Learning Experience			
	Yes	169	55.96%
	No	133	44.04%
Average Weekly Time Spent Using Electronic Devices for Learning			
	Less than 1 hour	54	17.88%
	1-3 hours	127	42.05%
	3-8 hours	94	31.13%
	More than 8 hours	27	8.94%
Average Weekly Frequency of Using Digital Products for Science and Innovation Education			
	More than 3 times per week	80	26.49%
	1-2 times per week	133	44.04%
	Occasionally	89	29.47%
Duration of Using This Type of Digital Learning Product			
	Less than 6 months	62	20.53%
	6 months to 1 year	84	27.81%

Variable	Category	Number (N)	Percentage (%)
	1-2 years	90	29.80%
	More than 2 years	66	21.85%
Whether Having Used AI-Assisted Learning Tools			
	Frequently used	61	20.20%
	Occasionally used	90	29.80%
	Rarely used	99	32.78%
	Never used	52	17.22%
Whether Having Used Paid Digital Learning Products for Science and Innovation Education			
	Yes	76	25.17%
	No	226	74.83%

4.1.3 Descriptive Statistics of the Variables

Descriptive statistics of each variable are shown in Table 4. The mean values of perceived enjoyment (PE), perceived usefulness (PU), perceived ease of use (PEOU), attitude to use (ATU) and behavioral intention (BI) were 3.7781, 3.8427, 3.5874, 3.7823 and 3.5579, respectively, all of which exceeded 3.5, indicating that students had a positive evaluation of the digital products of science and innovation education as a whole. Among them, the mean value of perceived usefulness is the highest, reflecting that students have the highest recognition of the function of such products to promote scientific learning and knowledge understanding; perceived enjoyment is second, showing that the product as a whole has a certain attraction. In contrast, the mean values of perceived ease of use and behavioral intention are low, suggesting that there is still room for improvement in operational convenience and users' willingness to continue using products. The skewness value is negative, indicating that the score is concentrated on the high end of the scale.

Table 4. Descriptive Statistics of the Variables

Variable	N	Range	Minimum	Maximum	Mean	Standard Deviation	Variance	Skewness	Kurtosis
PE	302	4.00	1.00	5.00	3.7781	0.76740	0.589	-0.615	0.176
PU	302	3.50	1.50	5.00	3.8427	0.72343	0.523	-0.328	-0.160
PEOU	302	3.60	1.20	4.80	3.5874	0.78082	0.610	-0.469	-0.249
ATU	302	3.00	2.00	5.00	3.7823	0.69942	0.489	-0.463	-0.130
BI	302	3.50	1.50	5.00	3.5579	0.71321	0.509	-0.253	-0.056

4.2 Reliability and Validity Analysis

In this study, Cronbach's α was used to evaluate the internal consistency reliability of the five construct measurement scales. The results showed that the α values of each construct ranged from 0.70 to 0.90, and the CITC values were higher than 0.670. The deletion of any item did not lead to an increase in the α value of the corresponding scale, indicating that all items were highly correlated with the construct and had a positive contribution to the overall reliability. In summary, the internal consistency reliability of the questionnaire is good, the data is reliable, and it is suitable for the subsequent validity test.

Table 5. Reliability Analysis

Construct	Cronbach's α
PE	0.898
PU	0.868
PEOU	0.875
ATU	0.858
BI	0.728

The validity of the questionnaire was assessed using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity for all questionnaire items. The results showed that the KMO values for all constructs ranged from 0.823 to 0.878, all exceeding 0.80, indicating that the data were highly suitable for factor analysis. In addition, the p-values of Bartlett's test of sphericity were all 0.000 ($p < 0.001$), suggesting that the correlation matrices differed significantly from the identity matrices and that the questionnaire items were appropriate for factor analysis. The factor analysis further showed that the communalities of all items exceeded 0.60, indicating that the variables were well explained by the common factors. These results demonstrate that the questionnaire possesses good construct validity.

Table 6. KMO Measure and Bartlett's Test of Sphericity

Construct	KMO	Bartlett's Test of Sphericity (p-value)
PE	0.844	0.000
PU	0.823	0.000
PEOU	0.878	0.000
ATU	0.825	0.000
BI	0.822	0.000

4.3 Correlation Analysis

To examine the significance of the relationships among the research variables, Pearson's correlation analysis was conducted. The Pearson correlation coefficient is used to measure the strength and direction of the linear relationship between two variables, with values ranging from -1 to 1.The results of the correlation analysis are presented in Table 7. The findings indicate that Perceived Enjoyment (PE), Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude Toward Use (ATU), and Behavioral Intention (BI) are all significantly correlated with one another.

Table 7. Correlation Analysis Results of the Variables

Variable	Perceived Enjoyment (PE)	Perceived Usefulness (PU)	Perceived Ease of Use (PEOU)	Attitude Toward Use (ATU)	Behavioral Intention (BI)
Perceived Enjoyment (PE)	1				
Perceived Usefulness (PU)	0.207**	1			
Perceived Ease of Use (PEOU)	0.248**	0.171**	1		
Attitude Toward Use (ATU)	0.314**	0.518**	0.316**	1	
Behavioral Intention (BI)	0.285**	0.403**	0.346**	0.656**	1

4.4 Model Testing and Hypothesis Verification

4.4.1 Confirmatory Factor Analysis

(1) Convergent Validity Test

Table 8. Factor Loading Values of Each Construct

Construct	Number of Items	Average Factor Loading	CR	AVE	CR ≥ 0.7	AVE ≥ 0.5
Perceived Usefulness (PU)	4	0.7887	0.8685	0.6231	Yes	Yes
Perceived Ease of Use (PEOU)	5	0.7644	0.8757	0.5852	Yes	Yes
Perceived Enjoyment (PE)	4	0.8295	0.8986	0.6893	Yes	Yes
Attitude Toward Use (ATU)	4	0.7740	0.8569	0.5998	Yes	Yes
Behavioral Intention (BI)	4	0.7667	0.8513	0.5892	Yes	Yes

As shown in Table 8, the average standardized factor loads of the observed variables of perceived usefulness, perceived ease of use, perceived pleasure, attitude and behavioral intention were all higher than 0.6, the combined reliability (CR) was greater than 0.7, and the average variance extraction (AVE) was greater than 0.5, indicating that the measurement model was reasonable. Each item can effectively reflect its corresponding latent variables, internal consistency and explanatory power are up to standard, model reliability and convergence validity are good, which can support the subsequent structural model path analysis and intermediary effect test. The model fitting indexes were as follows : $\chi 2$ / df = 2.028 (0.8), GFI = 0.894 (> 0.8), TLI = 0.939, NFI = 0.902, CFI = 0.947 (all > 0.9), RMSEA = 0.058 (< 0.08). All indicators have reached the recommended standards, indicating that the measurement model fits well with the observation data, and the model setting is reasonable, which can be further analyzed by the structural model.

(2) Discriminant Validity Test

Table 9. Discriminant Validity Analysis Results among Variables

Construct	PE	PEOU	PU	ATU	BI
PE	0.8302				
PEOU	0.157	0.765			
PU	0.033	0.110	0.7894		
ATU	0.116	0.164	0.244	0.7745	
BI	0.129	0.149	0.212	0.290	0.7676

As shown in **Table 9**, the diagonal values represent the square roots of the **Average Variance Extracted (AVE)** values for each latent construct, while the lower triangular values represent the correlation coefficients between constructs. The results indicate that the correlation coefficients among the five latent variables—**Perceived Enjoyment, Perceived Ease of Use, Perceived Usefulness, Attitude Toward Use,** and **Behavioral Intention**—were mostly between **0.1 and 0.3**, indicating relatively weak correlations among constructs. Furthermore, the correlation coefficients between all constructs were significantly lower than the corresponding square roots of AVE, demonstrating that the measurement model had good **discriminant validity**.

(3) Measurement Model Fit Assessment

Table 10. Model Fit Criteria and Results of the Original Model

Fit Index	χ^2/df	AGFI	GFI	TLI	NFI	CFI	RMSEA
Evaluation Criteria	1-3	>0.8	>0.8	>0.9	>0.9	>0.9	<0.08
Observed Value	2.028	0.866	0.894	0.939	0.902	0.947	0.058
Model Fit	Good	Good	Good	Excellent	Good	Excellent	Excellent

The model fitting indexes were as follows : $\chi 2$ / df = 2.028 (0.8), GFI = 0.894 (> 0.8), TLI = 0.939, NFI = 0.902, CFI = 0.947 (all > 0.9), RMSEA = 0.058 (< 0.08). All indicators have reached the recommended standards, indicating that the measurement model fits well with the observation data, and the model setting is reasonable, which can be further analyzed by the structural model.

4.4.2 Structural Model Analysis and Hypothesis Testing

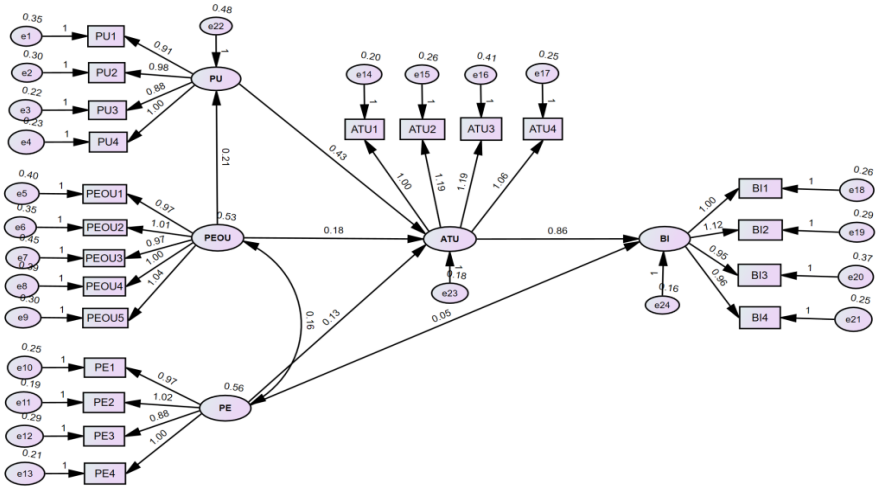

Figure 2. Structural Equation Model

Table 11. Path Results of the Structural Equation Model

Dependent Variable	Relationship	Independent Variable	Standardized Coefficient	S.E.	C.R.	P
Perceived Usefulness	←	Perceived Ease of Use	0.212	0.065	3.198	0.001
Attitude Toward Use	←	Perceived Ease of Use	0.228	0.046	3.866	***
Attitude Toward Use	←	Perceived Usefulness	0.538	0.051	8.435	***
Attitude Toward Use	←	Perceived Enjoyment	0.172	0.044	2.998	0.003
Behavioral Intention	←	Perceived Enjoyment	0.061	0.046	1.135	0.256
Behavioral Intention	←	Attitude Toward Use	0.764	0.079	10.947	***

According to **Table 11**, **Perceived Ease of Use** significantly and positively predicted **Perceived Usefulness** ($\beta = 0.212$, $p = 0.001$) and **Attitude Toward Use** ($\beta = 0.228$, $p < 0.001$). **Perceived Usefulness** had a significant positive effect on **Attitude toward Use**, with the strongest influence among all paths ($\beta = 0.538$, $p < 0.001$). Meanwhile, **Perceived Enjoyment** significantly and positively influenced users' **Attitude Toward Use** ($\beta = 0.172$, $p = 0.003$). **Attitude toward Use** also demonstrated a strong positive effect on **Behavioral Intention** ($\beta = 0.764$, $p < 0.001$).

Therefore, the following hypotheses were supported:

H1: Perceived Enjoyment positively influences learners' attitudes toward using digital products for science and innovation education.

H4: Perceived Usefulness positively influences learners' attitudes toward using digital products for science and innovation education.

H6: Perceived Ease of Use positively influences Perceived Usefulness of digital products for science and innovation education.

H7: Perceived Ease of Use positively influences learners' attitudes toward using digital products for science and innovation education.

H9: Attitude Toward Use positively influences learners' behavioral intention to use digital products for science and innovation education.

However, the direct effect of **Perceived Enjoyment** on **Behavioral Intention** did not reach statistical significance ($\beta = 0.061$, $p = 0.256 > 0.05$). This indicates that perceived enjoyment does not directly promote users' behavioral intention; instead, it influences usage intention indirectly through **Attitude toward Use**.

Therefore:

H2: Perceived Enjoyment positively influences learners' behavioral intention to use digital products for science and innovation education.

This hypothesis was not supported.

Overall, most of the hypothesized paths in the model were supported by empirical data, and the relationships among variables were consistent with theoretical expectations.

4.5 Mediation Effect Analysis

Table 12. Mediation Effect Test Result

Path	Effect Type	Estimate	Product of Coefficients		Bootstrapping Bias-corrected 95% CI		Conclusion
			SE	Z	Lower	Upper	
Perceived Usefulness → Attitude Toward Use → Behavioral Intention	Indirect Effect	0.373	0.047	7.936	0.289	0.473	Full Mediation
Perceived Ease of Use → Attitude Toward Use → Behavioral Intention	Indirect Effect	0.154	0.043	3.581	0.072	0.24	Full Mediation
Perceived Enjoyment → Attitude Toward Use → Behavioral Intention	Indirect Effect	0.113	0.04	2.825	0.042	0.2	Full Mediation
Perceived Enjoyment → Behavioral Intention	Direct Effect	0.053	0.048	1.104	-0.038	0.149	Not Significant

According to the mediation effect test results in Table 12, the indirect effect coefficient of Perceived Usefulness → Attitude Toward Use → Behavioral Intention was 0.373 (0.43 × 0.86). The 95% Bootstrap confidence interval for the indirect effect was [0.289, 0.473], which did not include zero, indicating that the mediation effect was significant. Since the model did not establish a direct path from Perceived Usefulness to Behavioral Intention, no significant direct effect was identified. Therefore, Attitude Toward Use plays a full mediating role between Perceived Usefulness and learners' behavioral intention to use digital products for science and innovation education.

The indirect effect coefficient of Perceived Ease of Use → Attitude Toward Use → Behavioral Intention was 0.154 (0.18 × 0.86). The 95% Bootstrap confidence interval was [0.072, 0.240], which did not include zero, indicating a significant indirect effect. Since the model did not include a direct path from Perceived Ease of Use to Behavioral Intention, no direct effect was observed. Therefore, Attitude Toward Use fully mediates the relationship between Perceived Ease of Use and Behavioral Intention. Meanwhile, Perceived Ease of Use had a significant positive predictive effect on Perceived Usefulness ($\beta = 0.207$, 95% CI = [0.078, 0.351]), supporting H6.

The mediating effect test showed that the indirect effect coefficient of perceived pleasure → use attitude → behavioral intention was 0.113 (0.13 × 0.86), and the 95% Bootstrap confidence interval was [0.042, 0.200], excluding 0, the indirect effect was significant. The direct effect coefficient of perceived pleasure on behavioral intention was 0.053, and the 95% confidence interval was [-0.038, 0.149], including 0, the direct effect was not significant. This shows that the use attitude plays a complete mediating role between perceived pleasure and behavioral intention, that is, perceived pleasure cannot directly drive the use intention, but can indirectly promote the use attitude by shaping a positive use attitude.

Overall, Attitude Toward Use significantly and positively predicts Behavioral Intention, and all three perception dimensions influence usage intention through the mediating role of Attitude Toward Use. Among them, Perceived Usefulness demonstrates the strongest mediation effect, followed by Perceived Ease of Use, while Perceived Enjoyment shows the weakest mediation effect.

Therefore, the following hypotheses were supported:

H3: Perceived Enjoyment has a positive mediating effect on learners' behavioral intention to use digital products for science and innovation education through Attitude Toward Use.

H5: Perceived Usefulness has a positive mediating effect on learners' behavioral intention to use digital products for science and innovation education through Attitude Toward Use.

H8: Perceived Ease of Use has a positive mediating effect on learners' behavioral intention to use digital products for science and innovation education through Attitude Toward Use.

Based on the above empirical analysis results, 8 of the proposed hypotheses were supported, while 1 hypothesis was not supported.

4.6.2 Factors Influencing Middle School Students' Use of Multimodal Digital Products for Science and Innovation Education

The results of the structural equation model show that perceived usefulness, perceived ease of use and perceived pleasure all have a significant positive impact on the use attitude, among which perceived usefulness has the greatest impact, indicating that educational value is still the primary factor in students' adoption decision-making. Perceived ease of use not only directly improves attitude, but also has an indirect impact by enhancing perceived usefulness, which is consistent with the expectation of TAM theory, indicating that intuitive operation and humanized interface design help to strengthen students' recognition of the value of product education. Although perceived pleasure significantly improves the attitude of use, it has no significant direct impact on behavioral intention, indicating that pleasure plays a more supportive role than a decisive factor. As an educational tool, students pay more attention to learning effectiveness. Under the pressure of examinations and competitions, it is difficult for entertainment functions to drive the willingness to continue to use alone.

In terms of specific hypothesis testing: perceived usefulness has a significant positive impact on the attitude to use (support H4), the more students can perceive the practical value of the product, the more positive their attitude to use; perceived ease of use has a significant positive impact on perceived usefulness and attitude to use (support H6, H7). Complex interfaces or difficult operations will increase cognitive load, and students in lower grades or with weak digital literacy have lower tolerance for operational complexity, which is more likely to generate frustration and reduce enthusiasm for use.

4.6.3 The Mediating Role of Attitude toward Use

The mediation analysis showed that perceived usefulness, perceived ease of use and perceived enjoyment all indirectly affected behavioral intention (support H3, H5, H8) through the use of attitude, indicating that students first formed a comprehensive evaluation of the product from the three dimensions of usefulness, ease of use and pleasure, and then transformed into continuous use intention after the overall attitude was established. Among the three indirect effects, perceived usefulness is the strongest (0.373), perceived ease of use is the second (0.154), and perceived pleasure is the weakest (0.113), indicating that "identifying usefulness → forming attitude → generating intention" is the dominant path of user decision-making. Accordingly, publishers and technology providers should take improving the educational quality and practical value of learning content as the primary task, supplemented by optimizing interface design and interactive fluency to improve ease of use, and integrating pleasant experiences to enhance participation. The collaborative improvement of the three is the key to strengthening users' long-term adoption intention and maintaining market competitiveness.

5. Strategies for Optimizing Multimodal Digital Publishing for Science and Innovation Education

5.1 Content: Optimizing Multimodal Knowledge Organization

Perceived usefulness has the strongest influence on middle school students' attitudes and behavioral intentions. Learners are most concerned about whether products can really improve learning effectiveness, so content optimization should be given priority. Specifically, publishers should build a modular knowledge system with the help of knowledge maps or conceptual networks to help them form an overall cognitive framework based on curriculum standards, cognitive development laws and project-based learning needs ; at the same time, according to the characteristics of learning content, text, image, audio and video, 3D models and AI resources are organically integrated to make multimodal elements complement each other to optimize knowledge presentation. And establish a dynamic update mechanism, timely incorporate cutting-edge achievements, innovative projects and competition resources, and enhance the timeliness and practical value of knowledge services.

5.2 Users: Improving Learning Support throughout the Learning Process

Perceived ease of use directly affects attitudes and enhances perceived usefulness. Therefore, products should establish a full-process learning support system while providing high-quality content. Specifically, it includes: designing differentiated paths and embedding phased tasks according to

students' age, knowledge level and learning objectives to ensure learning coherence; with the help of artificial intelligence technology, combined with learning data and knowledge mastery, intelligent question answering, diagnosis, reminding and personalized recommendation services are provided. At the same time, improve the feedback mechanism, through the combination of immediate feedback and formative evaluation, supplemented by learning records and ability portraits, to help students monitor progress and understand effectiveness.

5.3 Technology: Integrating Technology with Educational Goals

Although perceived pleasure can improve the attitude of use, it does not directly promote continuous use, indicating that technology application and entertainment functions must effectively serve learning goals to generate value. Therefore, the multimodal digital publishing of science and technology innovation education should integrate technology based on educational needs : artificial intelligence, virtual reality, big language model and other means should focus on knowledge acquisition, scientific inquiry and innovative practice, rather than simply displaying technology or entertainment functions; the points, badges, challenges and other mechanisms in the gamification strategy need to be deeply combined with learning tasks and knowledge assessment, so that students can achieve a sense of achievement through problem solving and activities; at the same time, based on the analysis of learning behavior data, accurate teaching support should be provided to improve the effectiveness of education.

5.4 Services: Building a Sustainable Knowledge Service System

Knowledge service requires continuous response to learning needs through continuous knowledge support and solutions. Therefore, the digital publishing of science and innovation education should establish a continuous service system covering all aspects of pre-school, middle school and post-school to extend the value of knowledge service. The specific measures are as follows: the platform needs to provide differentiated support according to different learning stages of students: the pre-school stage focuses on resource recommendation and learning planning, the learning stage focuses on intelligent guidance, feedback and practical guidance, and the post-school stage strengthens knowledge extension, ability evaluation and follow-up suggestions; at the same time, schools, science and technology museums, scientific research institutions and enterprises can be combined to integrate resources such as curriculum innovation projects to build an open and collaborative ecosystem. In addition, we should also promote the interaction and knowledge sharing between teachers and students and other participants through learning communities, themed activities, competitions and project-based learning mechanisms, enhance user participation and retention rates, and form a sustainable operation mode.

6. Conclusion and Future Research

The results show that perceived usefulness, perceived ease of use and perceived pleasure all have a significant positive impact on attitude, and then act on behavioral intention, among which perceived usefulness has the strongest impact. The research also reveals the shortcomings of current multimodal digital publishing in knowledge organization, learning support, technology integration and service system construction. Based on this, four optimization strategies are proposed - optimizing knowledge organization, strengthening whole-process learning support, integrating technology with educational goals, and building a sustainable service system - in order to provide a reference for product design and knowledge service improvement.

The limitations of the study are mainly reflected in two aspects: first, due to the limitations of time and sample acquisition conditions, the survey objects are concentrated in specific regions, and the representativeness is limited; second, the cross-sectional design is difficult to capture the dynamic changes of user behavior over time.

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