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AFFORDANCE-DRIVEN DESIGN FOR DIGITAL LEARNING

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ABSTRACT

This investigation delves into the utilization of digital math learning platforms from an affordance design perspective, aiming to pinpoint crucial elements that significantly enrich learning experiences within the digital realm. Through an in-depth dissection of ten specific affordances categorized into Content, Pedagogy, and Functionality domains, this study meticulously evaluates how these components are manifested across six digital platforms widely adopted within South Korean public education. Employing a comprehensive analytical approach, the research uncovers notable deficiencies in the integration of these essential affordances, with a particular focus on the widespread presence of Nonlinearity contrasted against the stark underrepresentation of Adaptivity. These findings illuminate a prevalent design-practice gap, suggesting that the pedagogical potential of digital learning tools is not being fully harnessed to facilitate enhanced learning outcomes. The analysis further reveals how the integration or lack thereof of these affordances impacts the efficacy of digital learning environments, suggesting a critical need for a more holistic integration strategy. Contributing a structured analytical framework to the ongoing discourse on digital education, this study not only highlights current shortcomings but also paves the way for the development of next-generation learning technologies. These advancements are envisioned to support diverse educational strategies more effectively, promoting dynamic and adaptive learning environments that can better cater to the evolving needs and preferences of students. This research advocates for a paradigm shift in the design and development of digital learning platforms, aiming to fully exploit the transformative potential of digital education in fostering more engaging, personalized, and effective learning experiences.

Keywords: *Affordance, Digital learning, Learning platform, Mathematics Education*

1. INTRODUCTION

Globally education at all levels is facing unprecedented and exciting change with the growth of learning platforms that leverage digital learning technologies as extensions of the physical classroom, accelerated by the COVID-19 pandemic and the rapid advancement of technology. South Korea has been at the forefront of integrating digital platforms into education, with a particular emphasis on enhancing math learning. According to the Ministry of Education in South Korea, over 80% of schools have adopted digital tools for teaching core subjects, with mathematics experiencing the highest integration rate. This shift signifies not only a change in the medium of instruction but also a fundamental reevaluation of pedagogical strategies to leverage the affordances offered by digital platforms.

Despite the widespread adoption of digital platforms, there remains a lack of clarity among educators and practitioners about which pedagogical theories should guide the evolution of teaching practices to fully leverage digital affordances [1]–[3]. Evans et al.'s view of affordance as "something that helps mediate behavior towards an outcome" (p. 36) means that an affordance is a characteristic of the learning space that promotes or facilitates learning outcome [4]. Since Gibson first used this term in 1979, the concept of affordance has been adapted in various fields and has resulted in various interpretations [5]. In particular, Norman emphasized the affordance of 'human-centered design' based on the ease of use of objects in the design field [6]. Moreover, the importance of affordance has been increasingly emphasized as the development of online-based media, such as the Internet and mobile, has rapidly progressed. Hartson provided a critical theoretical basis in that the affordance presented by Gibson and Norman could be classified into four types: physical, cognitive, sensory, and functional affordances so that they can be applied to human-computer interaction design [7].

1.1 Affordances in Digital Technology

The application of affordance in educational

technology is essential for understanding how different functionalities can foster desirable learning behaviors. Many research studies have employed Hartson's classification focusing on the interaction between computers and users. Kirschner and his colleagues proposed a significant affordance classification system within the context of e-learning technologies [8]. They categorized affordances into technological, social, and educational types, with educational affordances specifically representing the characteristics of educational resources that determine whether and how certain learning behaviors can be enacted in context. This classification system underlines the potential of technology to match learning tasks effectively and enhance the educational experience. Markus & Silver defined functional affordances as the potential goal-oriented actions that artifacts offer to specific user groups [9]. This definition highlights the relational aspect of affordances, emphasizing that they are not rooted in the artifact's individual features but emerge from the interaction between the object and the user. Furthermore, the concept's core lies in its relational nature – affordances do not exist independently of the object or the person. They are revealed through the interaction of the object and its user [10]. This relational aspect is crucial in the design and evaluation of digital systems, as it requires a comprehensive understanding of both the artifact and its users. Still, the limitation was that the affordances were, in terms of design, not explicitly geared toward how digital technology helps learning, that is, the connection between technology and learning [11].

1.2 The Focus of the Study

This study explores affordance design in digital math learning platforms, unveiling the intricate relationship between technology's potential and educational outcomes. This research outlines the expansive scope of such platforms through a detailed analysis of various elements that contribute to effective digital learning. It spans instructional content delivery, engagement strategies, and adaptability features that modern educational technology offers. This breadth of analysis, anchored in the meticulous evaluation of commercially available platforms, illuminates the multifaceted nature of digital education, providing a comprehensive backdrop for understanding how different affordance elements are integrated. The exploration is grounded in the comprehensive understanding that Bower [9] and Selwyn [10] have contributed to emphasizing the transformative potential of digital learning environments and their capacity to reshape educational landscapes.

Employing an affordance perspective that focuses on the connection between technology and learning, this study aimed to identify a set of critical affordances for digital learning platforms, particularly in the context of K-12 mathematics education. This endeavor was conducted through an in-depth literature review. Moreover, the study examined how these identified affordances are addressed in some widely adopted math learning platforms by schools in South Korea. Given that commercial companies predominantly lead the development of many digital learning platforms in Korea, it becomes imperative to scrutinize whether the features of these commercially developed platforms align with educational objectives, thereby assessing their suitability for school education.

2. METHODOLOGY

2.1 Case

The present study is a case study [12] in that we examine six different math learning platforms that illustrate an emerging class of digital environments for secondary school mathematics. We define digital math learning platforms in relation to five distinct features: A digital math learning platform 1) is didactic in nature. In other words, it consists of different learning designs; 2) includes ready-made programs for students to use, which are adaptable to the curriculum for school mathematics; 3) offers programs that do not require facilitation or scaffolding by the teacher; 4) integrates technology that some may consider as AI technology, and; 5) provides not only programs, but also digital tools which can be used by teachers and students, for example, for the purpose of communication and self-monitoring. Some platforms only work on PCs, while others are available exclusively for tablets.

To understand the affordance elements of the math learning platform, six digital math learning platforms (A-F) were chosen for analysis. In selecting the six platforms, criteria focused on their adaptability to the South Korean secondary school curriculum, the absence of teacher facilitation, and the incorporation of AI technology. This selection process aimed to represent a broad spectrum of digital learning environments currently influencing secondary education in mathematics. The chosen platforms are comprehensive in terms of covering most (if not all) content areas (such as numbers and operations, algebra, geometry, functions, statistics, and probability) of the national curriculum for secondary school mathematics. In addition, we have chosen platforms that potentially positively influence student learning to increase the validity by constructing a critical case [13]. Hence, learning platforms mainly

consisting of fragmented content and/or repetitive training exercises have been excluded. For instance, when a particular platform had its extensive use of AI to personalize learning experiences but did not have a comprehensive coverage of the national curriculum, that platform was not included for analysis. All the platforms are commercially available.

2.2 Affordance Framework and Analysis

Reconstructed based on a review of related literature (e.g., [11, 16]), a total of 10 affordances were categorized into three domains: Content, Pedagogy, and Functionality. The Content domain includes affordance elements (Nonlinearity, Linked Representations, Choice) related to subject content, such as learning materials and learning methods directly related to learners' math learning activities. The Pedagogy domain consists of affordance elements (Interactivity, Feedback, Reward) closely related to the role of teachers in class, while the Functionality domain is classified as affordance elements (Adaptivity, Open Input, Collaboration, Easy to Use) related to the function of the installed platform itself in connection with the use and convenience of the platform. Each affordance element was then illustrated with its specific, relevant features, fundamental to its definition and function. This categorization of affordances for digital math learning platforms is summarized in Table 1.

Table 1: Affordance Categories.

Domains	Affordances	Descriptions
Content	Nonlinearity	Allows the student to select or receive learning activities in an order that deviates from a set order
	Linked Representations	Provides quick connections between representations for topics
	Choice	Gives students options for what to learn and how to learn
Pedagogy	Interactivity	Systemically responds to actions of the student
	Feedback	Gives feedback on the quality of the learner's performance including how the quality could be improved
	Reward	Encourages learning by providing reinforcement
Functionality	Adaptivity	Presents information contingent on the behavior, knowledge, and characteristics of the learner
	Open-Ended Input	Allows students to express themselves through natural language, drawing pictures, and other forms of communication
	Collaboration	Communicates with one or more persons
	Easy to Use	Makes facilities convenient, intuitive, and visually useful

For each platform, the degree of reflection was coded based on the affordance elements set in this study. The coding was undertaken by implementing those platforms and referring to each platform's manuals. To secure the reliability and consistency of coding, three education/IT experts discussed the results of quantifying the degree of reflection of each affordance element to 3, 2, 1, and 0 points. Afterward, each expert coded two types of platforms and then completed coding after consulting on the parts that were considered necessary for more discussion. An analysis of the platforms on the Feedback elements is presented in Table 2.

Table 2. An Analysis Of The Feedback Features.

Feedback features	Platforms					
	A	B	C	D	E	F
Providing solutions and explanations for student responses	3	2	2	1	2	3
Offering various perspectives of solutions	0	0	0	0	0	0
Providing quantitative information about student performance	3	3	2	3	1	3
Providing quantitative	0	1	0	2	3	0

information about student performance						
Offering suggestions for improvement	1	0	0	1	2	1

3. RESULTS AND DISCUSSIONS

3.1 Affordance Integration Across Platforms

Our analysis revealed that while Nonlinearity was prevalent across platforms, enabling students to navigate learning materials in a flexible order, Adaptivity—tailoring content to individual learner profiles—was notably lacking. For example, while platform C allowed for a degree of learner choice, its adaptivity features were rudimentary, failing to adjust to the learners' ongoing performance or preferences. This result was somewhat below the expectation, as adaptivity is increasingly emphasized in digital learning platforms. This gap suggests that despite technological advancements, digital platforms may not fully meet individual learning needs.

More specifically, all three domains- Content, Pedagogy, and Functionality- were similar in the 1-point range. Among them, the content aspect was the highest, with 1.65 points, followed by the teaching method aspect (1.17 points) and the functional aspect (1.10 points). Among the 10 affordance elements, nonlinearity (2.44 points) in Content and Easy to Use (2.22) in Functionality exceeded the two-point. The other elements of Content - Linked Reps (1.25) and Choice (1.25) - and all the elements in the Pedagogy domain -Interactivity (1.00), Feedback (1.22), and Reward (1.28) - are shown to be around the one-point range. Moreover, Functionality affordance elements except for Easy to Use - such as Adaptivity (0.80), Open Input (0.53), and Collaboration (0.87) did not exceed 1 point. Open Input was shown to be the lowest score among all the affordances. Since most platforms offer limited response types, there is a need for more diverse response methods to leverage online technology fully. Surprisingly, only half of the analyzed platforms provided an exercise book function, underscoring the need for features like handwriting recognition and voice recognition to enhance convenience and accessibility. Open Input thus has significant development potential. This result is visualized in Figure 1.

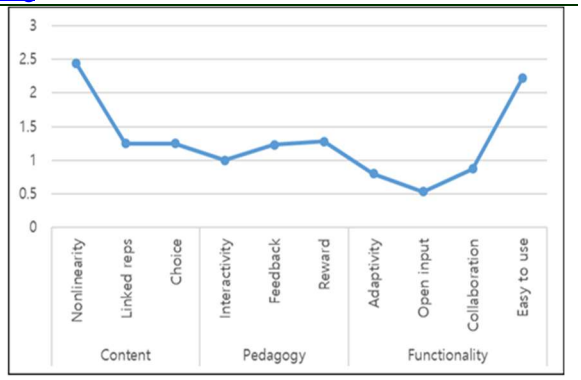

Figure 1: Affordance Integration Results Across Platforms

3.2 Affordance Integration By Platforms

In addition to the analysis of affordance integration across platforms, the overall levels of affordance integration by individual platforms are shown in Figure 2.

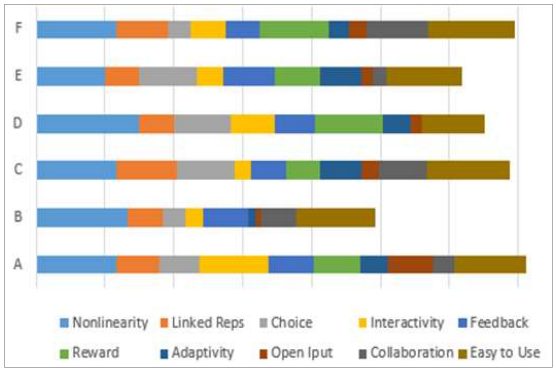

Figure 2: Affordance Integration Results By Platforms

The degree of reflection of affordance in the Content domain was found to be insufficient, with an average of 1.65 points. Most learning platforms present learning units or methods to be learned non-linearly. However, since the existing learning platforms have been developed for private education, focusing on practice in solving test questions, they showed low scores in Linked Reps. Therefore, it can be inferred that they need to develop many materials for learners to learn with various representations. Next, in Choice, while many platforms guarantee autonomy in choosing the learning units or methods, materials on various topics considering learners' interests are insufficient. In particular, they did not seem to consider when to explain according to the learner's choice, focusing just on explaining the problems.

The degree of reflection of affordance in terms of the Pedagogy domain was also found to be insufficient, with an average of 1.17 points, and all affordance elements classified into this category were insufficient in the 1-point range. Since most learning platforms are

still focused on providing questions without any role as a teacher, they pay attention to providing questions appropriately and telling whether the answers are correct or incorrect. The interaction between the learner and the platform, which considers both the cognitive and affective domains, is needed to improve the learner's understanding and immersion.

Similarly, in Feedback, most learning platforms provide a single explanation and limited quantitative and qualitative information. Still, it is necessary to provide more diverse feedback by designing and analyzing a function that collects various information, including the time required for each problem. In terms of Reward, Reward/Achievement elements, Competition elements, and Challenge elements are reflected in the order, which is expected to act as more effective ones if rewards such as points and badges are combined with providing multiple quests and missions.

The degree of reflection of affordance in the Functionality domain was the most insufficient among the three domains. Among them, Easy to use was the highest, followed by Collaboration, Adaptivity, and Open Input in order. Regarding the Easy to Use element, which received more than average scores, it seems that most learning platforms are paying attention to the functions so as not to cause inconvenience to the users. In Collaboration, some platforms had few related functions unless they were developed specifically for this, and this may also be because they focused only on providing problems. To provide better learning for the learning platform, it seems that a window for questions or communication is needed when the learner is curious.

3.3 Comparative Analysis from Prior Work

This study diverges from prior work on digital learning platforms, which has primarily concentrated on aspects of usability and user experience (e.g., [17], [18]), without a profound exploration of the pedagogical affordances that directly impact learning outcomes. Employing a structured affordance framework, our research uniquely integrates educational theory with technology design (e.g., [19]), marking a significant pivot from conventional analyses. This approach allows us to identify and underscore a critical gap in adaptivity and open-ended input within digital platforms, areas previously overlooked but crucial for enhancing personalized learning experiences. As shown in Table 3, our comparative analysis with existing literature highlights the potential for digital learning platforms to evolve beyond mere content delivery systems to become more adaptive, learner-centered environments.

Table 3. Comparative Analysis Of Platform Features.

Feature	Present Study	Prior Work	Gap Identified
Usability	Examined as part of a broader affordance framework	Focused on user interface and interaction design	Broader context in learning
User Experience	Integrated with pedagogical affordances	Emphasized for effective technology use	Need for educational alignment
Adaptivity	Highlighted as underrepresented	Not deeply explored	Critical for personalized learning
Open-ended Input	Identified as crucial for engagement	Overlooked in favor of structured responses	Essential for diverse responses
Pedagogical Affordances	Core focus: tied to educational theory and outcomes	Limited exploration	Key area for platform enhancement

4. CONCLUSIONS AND IMPLICATIONS

This study purports to explore the affordance of math learning platforms and map out the analysis criteria. After setting up the items considering the detailed elements of each affordance, we scrutinized six digital math learning platforms currently used in public education in South Korea, explored their functions, and examined how much the affordances were reflected in the platforms.

The primary contribution of this study lies in its systematic dissection of digital learning platforms through the lens of affordance theory, providing a nuanced understanding of how these platforms can better support mathematical education. By identifying a structured set of affordances and evaluating their presence in existing platforms, this research offers a novel perspective on designing digital learning environments that are both effective and engaging. Through a comprehensive analysis of six widely-used platforms, this research has uncovered significant gaps in the integration of essential affordances, particularly highlighting the disparities in the presence of adaptivity and open-ended input functionalities. These findings point towards a critical design-practice gap, suggesting that the potential of digital learning tools to enhance pedagogical outcomes is not yet fully realized.

Also, this research contributes significantly to the field of digital education by presenting a structured analytical framework for assessing the affordance

integration in digital learning platforms. It bridges the gap between educational theory and technology design [17], advocating for a more holistic approach to platform development. This framework can serve as a foundational guide for both researchers and developers in creating next-generation learning platforms that are more responsive to the diverse needs of learners. By shedding light on the specific affordances that are critical for engaging and effective digital math education, this research paves the way for the development of more refined and pedagogically sound learning platforms [20]. Furthermore, the identification of adaptivity and open-ended input as key areas for development presents a clear pathway for enhancing personalized learning experiences in digital platforms.

This study is not without its limitations. The analysis was confined to platforms used within the Korean educational context, which may limit the generalizability of the findings. However, its findings resonate broadly, underscoring the universal need for platforms that embrace a more holistic approach to integrating content, pedagogy, and functionality affordances. Additionally, the focus on commercially available platforms may have overlooked potential affordances present in emerging or non-commercial educational technologies. Future research should aim to broaden the scope of analysis to include a wider variety of digital learning environments and explore the long-term impacts of affordance integration on learning outcomes. Despite this study's methodical examination of digital learning platforms, we were studying digital platforms in isolation from their classroom application. That is, we were studying an artefact that is yet to be interpreted by teachers and students.

In conclusion, this study marks an important step towards understanding and improving the design of digital learning platforms. By focusing on the integration of pedagogically significant affordances, it contributes valuable insights into the creation of digital learning environments that not only engage learners but also support diverse educational strategies and outcomes. As we move forward, it is imperative that future research continues to build on these findings, exploring innovative ways to enhance the interplay between technology and learning in the digital age.

5. SUGGESTIONS FOR FUTURE WORK

Based on the findings and limitations of our study, especially in the context of mathematics education in South Korea, we offer several suggestions for future research that could extend and enrich this area of study.

First, future research could focus on longitudinal studies that measure the impact of affordance-driven digital learning platforms on student learning outcomes over time. This would help in understanding the long-term benefits and potential drawbacks of integrating specific affordances in digital math learning environments. Second, conducting comparative studies across different countries or educational systems could provide insights into how cultural, socio-economic, and educational policies influence the effectiveness of digital learning platforms. This could also explore how affordances need to be tailored to fit diverse learning environments and student needs. Third, investigating the perceptions and experiences of both teachers and students with these platforms could offer valuable feedback on their usability, effectiveness, and areas for improvement. This could include qualitative research methods such as interviews, focus groups, and case studies. Fourth, based on the identified gaps in current digital learning platforms, future work could involve the design and development of prototype platforms that better integrate the key affordances. This research could collaborate with educational technologists, teachers, and students to iteratively design, test, and refine these prototypes. Fifth, exploring the integration of advanced technologies such as artificial intelligence (AI) and machine learning in digital learning platforms could be a significant area for future work. Research could focus on how these technologies can enhance adaptivity, personalization, and interactive feedback, further improving learning experiences. Sixth, future studies should also consider the accessibility and inclusivity of digital learning platforms. Research could explore how these platforms can be designed to support learners with diverse needs, including those with disabilities, to ensure equitable access to high-quality math education. Lastly, another area for future research could be the scalability of affordance-driven designs and the challenges associated with their implementation in real-world educational settings. This could include studies on the technical, pedagogical, and logistical aspects of deploying and sustaining these platforms in schools.

By addressing these suggestions for future work, researchers and educators can continue to advance the field of digital learning, making it more effective, inclusive, and responsive to the needs of learners in the digital age.

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