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A historic site and museum guide system based on wearable mixed reality: effects on students' situational interest

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***Abstract*—This study proposed a mixed reality (MR)-based wearable guide system that enables students to learn MR virtual materials found throughout their real-world surroundings. This system adopted the HoloLens to realize a MR learning environment for facilitating hands-free use and avoiding interference with students' attention while walking around a historic site or museum. The goal of this study focuses on whether the MR-based wearable guide system is capable of raising students' situational interest when it is used in historic site and museum education. The situational interest scale, which consists of novelty, challenge, attention demand, instant enjoyment, exploration intention and total interest, is adopted to measure the learning interest of the students towards the proposed system. This study employed two museums as its research site and examined a total of 30 university students. The experimental results of this study indicated that situational interest has a positive effect, especially total interest and novelty dimensions. Therefore, the proposed system was able to effectively offer the feeling of freshness to the students and enhance their engagement when they encounter learning activities in a museum environment. For such informal learning environments, we believe that the proposed system can strengthen the interaction and the immersive perception between visitors and exhibition items.**

***Index Terms*—Wearable computers, augmented reality, virtual reality, mobile learning**

I. Introduction

Historic sites and museums generally are referred to as informal learning environments where visitors can freely attend and, thus, discover historical information [1, 2]. Such places are used to preserve many historical objects or physical artifacts from the past to the present, and also are considered as the heart of cultural values from the past [3]. Visiting historic sites and museums enables people to understand their history and also raise their long-term impression of historical events [4, 5, 6]. However, learning in historic sites and museums often involves change in background knowledge as visitors move from one historical object to another one. This situation easily interrupts the learning process of the two historical objects. In order to provide visitors with seamless and immersive learning experiences of historic sites and museums, mobile technologies are used to support visitors' access to information regarding historical objects while moving between physical objects [7, 8, 9]. Such technologies not only help visitors to learn on the move, but also give visitors more direct interactions with physical objects and more personal learning experiences.

With the current prevalence of personal mobile technologies, the integration of the Internet of things (IoT) and wearable devices into historic site and museum education is considered as one of the leading directions within next 5 years [4,10]. The global market for wearable devices grew by 82.3% in the year 2019 and is also anticipated to reach a new high of US$118.9 million devices shipped, according to new data from the International Data Corporation (IDC) and Worldwide Quarterly Wearable Device Tracker [11]. Ramon T. Llamas [11], research director for IDC's Wearables Team, pointed out that the year 2019 marked a strong step forward for the wearables market worldwide. Media Lab [12] asserted that wearable devices break the limitation of computer use and allow users to wear the computer on their bodies like normal clothing or eyeglasses. They also highlighted that wearable devices allow interaction based on the context of the situation. In other words, wearable technology usually incorporates smart sensors which are used to collect and measure the wearer's personal data, further giving them a more sophisticated and personalized experience [4, 10, 13, 14].

Some studies have developed applications of wearable devices in different fields, such as self-monitoring health management, medical education, and military training [15, 16, 17]; however, there are still relatively few applications of wearable device used in the field of historic site and museum education [4,18]. For example, Leue et al. [18] used Google Glass to simplify augmented reality (AR) application, which overlays virtual information on Google Glass for enhancing visitors' learning outcomes within art gallery environments. The results of the study showed that the use of wearable devices with hands-free operation provides more personalized and convenient learning experience when compared with the audio guide. The authors also asserted that Google Glass helps visitors to see connections between different paintings and further enhances visitors' knowledge, understanding, and interest. Yu et al. [4] used Google Cardboard and personal smartphones to develop an AR-based online wearable guide for supporting higher education and museums. The results of the study indicated that the proposed system can give a better situational interest and learning retention when compared with the audio guide. They also indicated that the hands-free feature of the proposed system is able to strengthen the interaction and the immersive perception between learners and exhibition items.

Although previous studies have used wearable devices in galleries and museum education, the adoption of wearable device in real-world learning environments is still challenging [4, 18, 19]. Johnson et al. [10] predicted a development timeline for the use of wearable devices in museum education, the timeline presents at least three years gap between the introduction of wearable devices in higher education and museum environments. It is easy to understand that due to the novelty factor of wearable devices, research focusing on these cutting-edge devices is scarce and difficult.

Moreover, various interests, such as active engagement, concentrating attention, and one's learning strategies play an important factor in determining human behavior in the learning

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process [4]. It also influences human emotional engagement in learning activities or tasks, and the extent of engaging in deeper processing [20]. Some researchers considered that interest is an interaction between an individual and an environment; thus, this interest can be classified into personal interest and situational interest [21, 22, 23]. Specifically, situational interest refers to interest triggered by environmentally activated and context-specific situations, further enhancing a learners' need to acquire knowledge when they interact with a specific situation [4]. Situational interest has currently been shown to positively influence cognitive performance, focus attention, and enable the integration of information with prior knowledge; thus, promoting and enhancing levels of learning [24, 25, 26].

Therefore, the use of wearable devices in galleries and museums might enhance interaction between supplementary multimedia information, physical exhibits, and the situational interest of learners, helping them to achieve a deeper understanding. The aim of this study is to combine mixed-reality (MR) learning material with wearable guides in order to facilitate historic site and museum education, and also further assess how wearable devices enhance visitors' situational interest in such learning environments. We hope that this study will contribute to the gap in research by investigating the opportunities of using wearable technologies to enhance learning performances within historic sites and museums.

II. Literature Review

A. *Wearable devices for learning*

Wearables devices refer to the integration of computing technology into a gadget that can be worn on the body, such as smart watches, sensor bands or similar devices. These devices usually incorporate smart sensors, connected to wearers, which can be used to measure personal data, track physiological information, as well as help them to achieve goals [4, 11, 12, 14]. For example, sensor bands can collect users' health-tracking data from the sensors that are embedded within it, and may offer a less intrusive means of monitoring their health [11, 12, 14]. Rhodes [27] defined five characteristics of wearable devices, including "portable while operational", "hands-free use", "sensors", "proactive", and "always on, always running". This means that wearable devices not only perform many basic computing functions, such as laptops and smartphones, but also provide more comfortable and easier to integrate computing services into users' lives without the need for additional electronic devices.

Currently, there are many studies attempting to integrate wearable devices into formal and informal learning environments as well as understand how wearable devices can be used to improve educational activities, particularly head-mounted displays [16, 19, 28]. For example, Lin et al. [19] proposed a head-mounted spherical video-based virtual reality (VR) guide system for university library learning. Their experimental result revealed that the proposed system has a positive impact on students' learning motivation and germane cognitive load as compared with the traditional mobile guide system. Ray and Deb [29] developed a VR-based wearable system through the use of Google Cardboard and personal smartphones to improve classroom teaching. The experimental result found that using the proposed system not only improves the learning process, but also enhances students' participation in learning. Incekara et al [30] used an accurate form of a wearable MR device for preoperative neurosurgical planning. Their experimental result found that learning brain tumor surgery planning with the head-mounted display was no different from standard neuronavigation in the operating room. This study offered proof of the clinical feasibility of wearable devices for brain tumor surgery planning in the operating room. Westerfield et al. [31] proposed an intelligent AR-based training system with the head-mounted display for learners to learn and retain assembly skills. Their evaluation found that such a teaching method can generate a beneficial educational effect in hardware components assembly courses.

Based on the foregoing, head-mounted displays are very suitable for the related applications of VR, AR, and MR. In the case of VR, AR, and MR heads-up displays, wearable devices are able to provide a wealth of new educational opportunities, enhancing the world around wearers [11, 12, 14]. MR refers to the use of a medium that merges real and virtual worlds to produce new environments and visualizations in which physical and digital objects co-exist and interact in real time [32]. This innovative technology provides a framework to position real and virtual worlds to develop new paradigms that allow for visualizations at different scales and the design of comparative mixed reality pedagogy across multiple disciplines [32, 33, 34]. Put simply, this means that MR is a hybrid of reality and VR and encompasses both AR and augmented virtuality (AV) by using immersive technology [32]. MR technology is already being applied to many different domains, including art, entertainment, military training, and medical and health education, among others [33, 35, 36].

Hughes et al. [36] considered that MR technology is suitable for real-world applications that usually require complex scenarios or content issues. Through the use of MR technology, the study developed a diverse urban terrain application for military training, situational awareness, and community learning; and the authors found that such method can significantly increase the entertainment, educational, and satisfaction levels of human experiences [36]. MR is a useful tool for educational training and application [33, 36]. Therefore, in this study, we chose to use a pair of smart glasses to realize a MR learning environment for facilitating hands-free use and avoiding interference with students' attention while walking around a historic site or museum.

B. *Microsoft HoloLens*

Microsoft HoloLens is a pair of mixed reality smart glasses developed and manufactured by Microsoft Company. This device was the first head-mounted display running the Windows MR platform under the Windows 10 computer operating system [37, 38]. It has an adjustable and cushioned inner headband, which can fit the HoloLens on users' heads and tilt their heads to different sides [37, 38]. Many of

Fig. 1. Microsoft HoloLens.

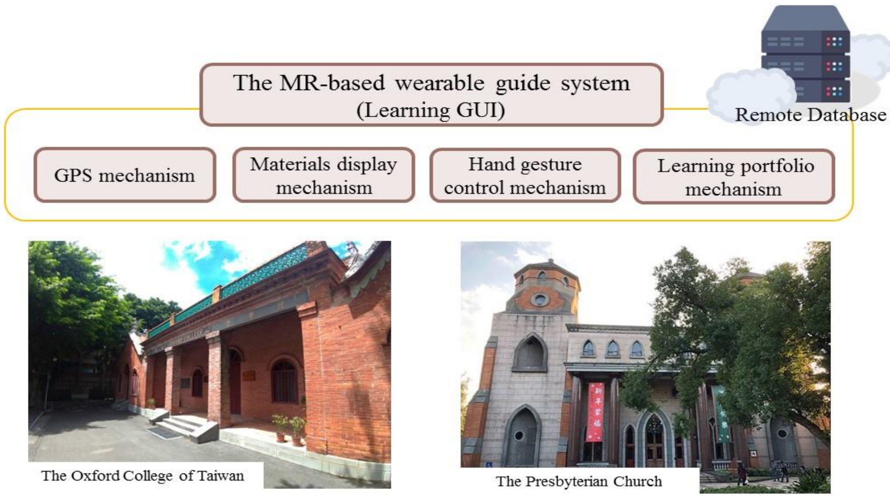


Fig. 2. System structure of the MR-based wearable guide system.

the sensors and related hardware are embedded in front of the HoloLens, including the processors, cameras, and projection lenses. The visor of the HoloLens is tinted and it can display virtual contents or projected images in the lower half, as shown in Figure 1.

Moreover, the HoloLens is able to track wearers' movements, watch their gaze and transform virtual contents by blasting light at wearers' eyes [39, 40]. Because it tracks the location of the wearer, the HoloLens wearer can use hand gestures and their finger to interact with virtual contents; that is to say, the HoloLens has plenty of sensors to sense the wearer's movements in a space. It uses this information along with layers of colored glass to create virtual contents that the wearer can interact with [39, 401]. Therefore, the HoloLens wearer is able to see the real-world and interact with virtual contents at the same time, and they also can walk around and talk to others without worrying about bumping into walls [39, 40].

Hence, this study attempted to adopt Microsoft HoloLens in historic site and museum education. Through the introduction of the HoloLens, an intuitive learning environment can be created in such a way that users are provided with hands-free devices; therefore, they can use their hands to interact with the MR-based learning contents. In other words, the HoloLens creates a more ideal immersive environment that enables users to view 3-D virtual objects, navigate whole physical artifacts, and interact with virtual content in real time without any interruptions. In a way, it can help museum visitors obtain a context-specific experience from environmental activation, understand the learning content of exhibitions on a deeper level, and further enhance visitors' situational interest during physical education. This study hopes that such a learning method will avoid interfering with the learning process of students when walking around a historic site or museum as well as accelerate the integration of wearable devices into informal learning environments.

C. *Situational Interest*

Situational interest concerns information that is of temporary value, environmentally activated, and context-specific, which includes text-based interest, task-based interest, and knowledge-based interest [20, 21]. Text-based interest is regarded as aspects of text used to affect learners' interest; task-based interest concerns task manipulations or encoding instructions that can increase learners' interest; knowledge-based interest is regarded as aspects of the learners' knowledge base that are used to enhance learners' interest [20]. Hidi and Renninger [24] suggested that the development of learning interest is based on the foundation of situational interest, which can support learners in gradually building up a long-term individual interest over time; meanwhile, situational interest can be regarded as a kind of spontaneous interest that fades away as rapidly as it emerges, and is always generated by place-specific situations [20].

According to the above-mentioned descriptions, the learning environment is a critical factor for developing learners' situational interest [4, 41]. Garcia et al. [41] emphasized that the learning environment is able to develop students' situational interest, and teachers can lead students' feedback on situational interest through the use of different teaching methods, which can increase classroom attention and interaction. In this manner, teachers might could evoke students' curiosity in the learning environment, and thus, grasp and maintain their attention [35].

In order to verify situational interest in physical education, Chen et al. [42] developed a scale of situational interest that is used to understand how students perceive physical activities. This scale consists of six dimensional sources: novelty, challenge, attention demand, instant enjoyment, exploration intention, and total interest [42]. "Novelty" is conceptualized as the size of the gap between information that is known and unknown; "challenge" is defined as the level of difficulty relative to an individual ability; "attention demand" is represented as the power of stimulation offered by the activity; "instant enjoyment" is defined as the degree of enjoyment experienced during the activity; "exploration intention" is conceptualized as the mental disposition to exploration; "total interest" is defined as eliciting learners' overall evaluation of situation interest in the activity [4, 42].

Therefore, this study attempts to investigate whether the MR-based wearable guide system for historic site and museum education is able to trigger situational interest. We also adopted the scale of situational interest proposed by Chen et al [42] to evaluate learners' situational interest when they used the proposed system during physical activities.

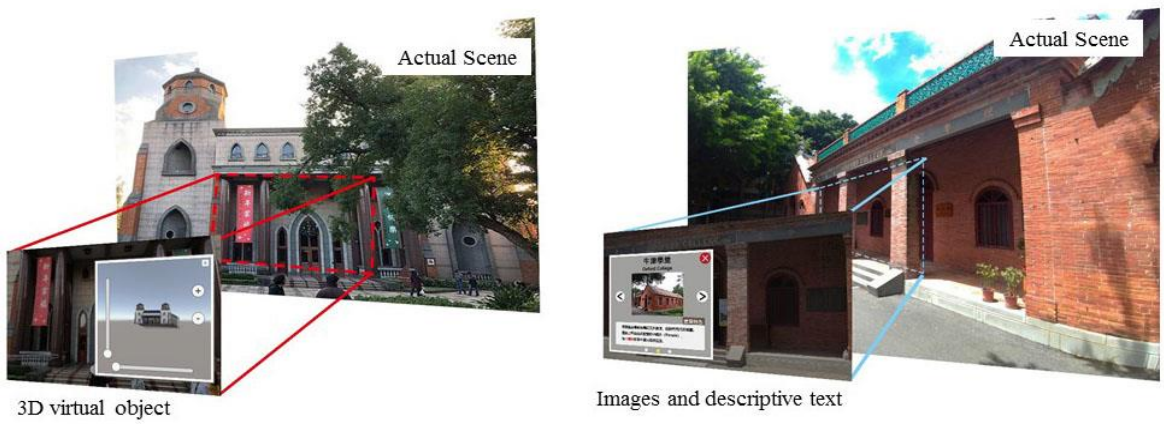


Fig. 3. The example of multimedia materials displayed on the HoloLens.

III. Research Methodology

A. *The MR-based wearable guide system*

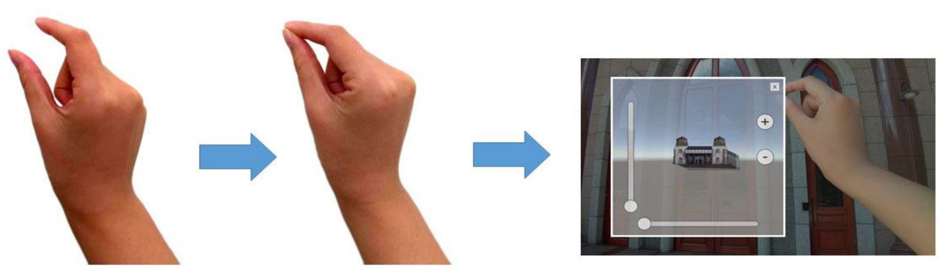
The MR-based wearable guide system was developed using C# and Microsoft SQL server, and is compatible with Windows 10 platform. Students using the HoloLens pre-installed with the proposed system can learn the MR-based learning contents found throughout their real-world surroundings.

Figure 2 shows the structure of the MR-based wearable guide system that was used to introduce the history of two museums including the Oxford College of Taiwan and the Presbyterian Church. It consists of a GPS mechanism, a materials display mechanism, a hand gesture control mechanism and a learning portfolio mechanism, as well as a remote database that provides multimedia materials for individual wearers and records their personal profiles. When the GPS mechanism detects the location of wearers that have available MR-based learning contents, the corresponding multimedia materials of the historical object is accessed from the remote database. Once the download of multimedia materials is complete, the materials display mechanism employs the Learning GUI to display the relevant learning content onto the visor of the HoloLens. The multimedia materials are composed of videos, images and 3D virtual objects, as shown in the bottom of Figure 3.

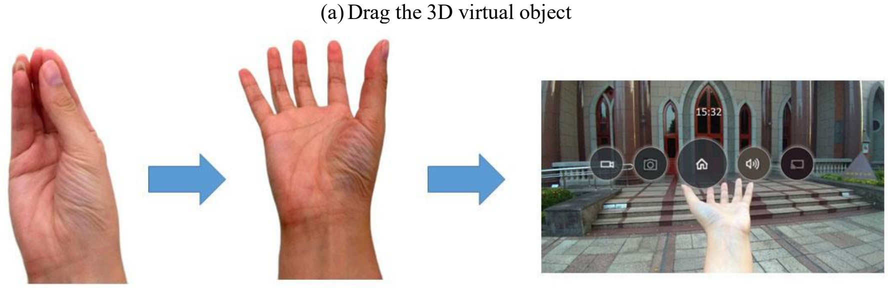
The hand gesture control mechanism enables wearers to control the learning materials by using their hand (e.g. switch screen, drag or touch material, etc.), allowing for more control over their learning pace. Figure 4(a) shows that the wears how to use his/her hand to drag the multimedia materials; Figure 4(b) show that wears how to use his/her hand to switch to the homescreen of the Hololens. Then, the learning portfolio mechanism can monitor the overall learning process of individual wearers, which is recorded in the remote database.

B. *Research participants*

This study was conducted with the consent of a professor of the "History and Religions of Tamsui" curricula that was taught at the Aletheia University in northern Taiwan. The course is officially offered through the general education center of this private university, and it was specifically created to introduce historical monuments located in the north of Taiwan. In this curricula, the targeted museums were used to present important artifacts and historical contributions left behind by Dr. Mackay, as well as introduce his personal stories. In this study, the MR-based learning contents are designed for describing the impressive lifetime achievements of Reverend George Leslie Mackay and his various contributions to Taiwanese culture and



(a) Drag the 3D virtual object



(b) switch to the homescreen

Fig. 4. The example of using hand to control the learning material.

Fig. 5. Students using the MR-based wearable guide system.

society. As museums are informal learning environments, this study recruited 30 university students (17 men and 13 women) who were at least 20 years of age and willing to participate in the experimental activities. No students were privy to the instructional method in advance.

C. Experimental design

At the start of the experimental procedure, all student participants were asked to sign a consent form that indicated their willingness to participate in the study, and that they could also withdraw from the experimental process at any time. After 10 min of instruction on the use of the equipment and ensuring that the devices were working normally, a learning activity of approximately 30 min was conducted for each student. Since we only had three pieces of equipment, this study divided all student participants into ten sub teams to circumvent disturbances caused by other external factors, such as defective devices, unstable wireless connections, or a limited amount of learning spaces and equipment, to mention a few. Each sub-team was overseen by two researchers who monitored each step during the learning activity and guided the students to finish visiting the route.

Student participants wore the HoloLens on their heads and moved freely within two museums during the learning activity as shown in Figure 5. Eight MR-based learning contents were presented to the students, which included video introductions, photographs and descriptive text, and 3-D synthetic objects like historical building models. After the learning activity, each student was required to take 10 minutes to complete the questionnaire that surveyed their situational interest. In the final step of the study, we invited eight student participants to provide some feedback relating to their individual experience with the instruction method, and each student was interviewed for 5 to 10 minutes in order to offer their feelings about using the proposed system.

D. Research instruments

This study designed a questionnaire on students' learning interest by referring to the definition of situational interest scale developed by Chen [42]. We also modified activity names in accordance with the experimental situation. Six dimensions of situational interest were measured in the questionnaire: "Novelty", "Challenge", "Attention demand", "Instant enjoyment", "Exploration intention" and "Total interest". It consists of 24 items on a conventional 5-point Likert-scale and each dimension is represented by four items. The Cronbach's alpha value of each dimension was 0.89, 0.95, 0.89, 0.89, 0.90, and 0.89, respectively. These values show good reliability in internal consistency. Through the use of the questionnaire survey, we hope that the MR-based wearable guide system is helpful in triggering the situational interest of university students with its novelty and uniqueness.

IV. Experimental Results

As mentioned previously, this study adopted the situational interest scale to evaluate the learning interest of the students towards the proposed system. The experimental results of the situational interest scale have been summarized in Table I.

TABLE I
THE RESULTS OF SITUATIONAL INTEREST SCALE

Variables	*M*	*SD*
Novelty	4.50	0.50
Challenge	3.86	1.02
Attention demand	3.88	0.65
Instant enjoyment	3.98	0.73
Exploration intention	3.76	0.77
Total interest	4.26	0.56

Table I shows that the mean value of the total interest dimension is 4.26, so generally speaking, the overall situational interest of students was promoted with the MR-based wearable guide system. The highest mean score yielded was seen for the novelty dimension ($M = 4.50$), conceptualized as the size of the gap between familiarity and unfamiliarity, and it has a function to motivate human beings' exploratory behavior [4, 39]. From the interviews of the students, all participated interview students indicated that because of the hands-free operation of the devices, they can directly touch and move multimedia materials using their hand. They were surprised by such learning method and considered it easy to use and master. Five participated interview students indicated that the proposed system was able to effectively provide the feeling of freshness to the participants and enhance their engagement when they encountered learning activities in a museum environment.

The lowest mean score was obtained from the exploration intention ($M = 3.76$) regarded as the mental disposition for exploration, and also representing the power of stimulation that can likely arouse a learner's instant perception of situational interest in the learning activity [4, 42]. From the interviews of the students, three participated interview students indicated that the HoloLens was too heavy for them, so they could not wear it for a long time when walking around the museum. It is possibly why the participants were unwilling to explore more learning contents through using the proposed system as it could have caused the split-attention and frustrating effects observed.

V. Conclusion

This study explored whether the MR-based wearable guide system is feasible in stimulating students' situational interest when used in historic sites and museum environments. In summary, the hands-free features of the proposed system and the MR-based museum guide capabilities were successfully applied to museum education. With regard to learning interest, the experimental result showed a positive effect with the overall situational interest, especially in the novelty and total interest dimensions. The novelty dimension is related to past experience and newly obtained information [19]. During the learning activity, the MR-based wearable guide system enables students to interact with multimedia materials with hands-free operation and view 3-D virtual objects through ones' own eyes; thus, the proposed system creates an intuitive learning environment that provides students with a feeling of novelty, which is not a common experience. This situation was also presented from the interviewed results; the students expressed that they felt freshness and uniqueness when they used the proposed system to learn the content of historical objects, which might facilitate the effect of raising total interest dimension. Several previous studies have similarly reported that overlaying virtual materials on head-mounted displays for physical education might significantly increase the elements of novelty and total interest within situational interest [4, 19]. Hence, such result proved that our MR-based wearable guide system can be effectively used in historic site and museum education, and can enhance the immersive perception between visitors and physical objects.

Each Microsoft HoloLens costs 3500 US dollars, which is an expensive device for historic site and museum education. This creates a situation where the goal of universal use of wearable devices for historic site and museum may not be easily achieved. We believe that the HoloLens is more suitable for special exhibition contents, in which visitors need to deeply interact with and understand physical objects. It is recommended that future works related to this topics focus on what kind of learning contents would be appropriate for the introduction of the HoloLens. Moreover, it is necessary to further evaluate students' learning performance in quizzes before/after learning activities. This statistical analysis can be used to explore whether the MR-based wearable guide system is helpful in regard to learning effect or any other novelty effect.

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