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THE EFFECTS OF COMBINING INQUIRY-BASED TEACHING WITH SCIENCE MAGIC ON THE LEARNING OUTCOMES OF A FRICTION UNIT

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Abstract. *This research used a quasi-experimental method to explore whether integrating Science Magic (SM) into 5E Learning Cycle (5ELC) in the development of teaching materials for a friction unit would impact students' learning outcomes and attitudes toward science. A total of 68 eighth-grade students were divided into experimental and control groups. The experimental group was taught using teaching materials and methods developed using the SM-based 5ELC, while the control group adhered solely to textbook-based materials, which were also based on the 5ELC but did not involve SM activities. Two major findings were obtained in this research. First, learning effects for the experimental group were significantly higher than the control group, especially in relation to characteristics of static friction, factors that affect friction, and relationships between frictional and normal force. Second, the experimental group showed significant improvements in their attitudes toward science when juxtaposed with the control group.*

Keywords: *attitudes toward science, friction concepts, inquiry-based teaching strategy, science magic.*

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Introduction

Magic is perceived as entertaining because of its surprising results, which contradict observers' expectations. Many magic tricks are based on the rules of natural science, and incorporate ingenious designs and skillful acts to create false impressions that arouse audience curiosity. Consequently, magic and science are closely related in terms of the knowledge involved, and each trick's underlying principle should conform to the laws of natural science. Hsu, Huang, and Yang (2010) define Science Magic (SM) as a performance utilizing changes in natural phenomena to confound audience intuition. While SM is based on scientific principles, it differs from chemistry or physics experiments; SM covers scientific principles uniquely and mysteriously to amaze observers. Interest in SM has recently increased, and numerous books concerning it have been published (cf. *Magic Science: 50 Jaw-Dropping, Mind-Boggling, Head-Scratching Activities for Kids* by Wiese; *It's Not Magic, It's Science!: 50 Science Tricks that Mystify, Dazzle & Astound* by Buttitta, La Baff, and Lundgren; and *Science Magic Tricks* by Shalit).

From a science education viewpoint the entertaining nature of SM can be efficiently employed to arouse curiosity; effective learning activities can be developed by exploring the scientific principles and knowledge that underlie magic tricks. However, earlier applications of SM to teaching focused solely on tricks and deciphering magic techniques. While the aforementioned approach is popular among students due to its entertaining features, research examining the integration of magic tricks into inquiry-based learning is lacking. It is preliminarily hypothesized that the integration of multiple SM tricks and appropriate teaching strategies would significantly increase learning effectiveness, as well as student attention, learning interest, and motivation to perform inquiry.

The 5E Learning Cycle (5ELC) was first proposed by Bybee and Landes (1988), who emphasized the active construction of knowledge and divided the learning cycle into five stages: engagement, exploration, explanation, elaboration, and evaluation. At each stage, students are encouraged to develop the uniqueness, fluency, flexibility, and precision necessary for effective thinking. This research thus employs the 5ELC as a teaching strategy in designing effective SM learning materials for a friction unit targeting junior high school students, while simultaneously exploring SM's effects on learning achievement and science attitudes.

Magic Performance in Science Education

Magic performances are built upon captivating audience attention and awareness in order to manipulate observers' beliefs and perceptions (Macknik, King, Randi, & Robbins 2008). Contemporary research investigating magic from a scholarly perspective is abundant. For example, Kuhn, Tatler, Findlay, and Cole (2008) and Tatler and Kuhn (2007) examine precisely how magicians deceive audiences. Demacheva, Ladouceur, Steinberg, Pogossova, and Raz (2012) and Kuhn, Amlani, and Rensink (2008) explore the relationship between magic and cognitive psychology, while Subbotsky (2011) compares people's beliefs concerning magic to science.

Despite the research cited above, studies in science education exploring the integration of SM with certain teaching strategies remain sparse. The limited research that does exist, however, indicates that combining teaching with appropriately designed SM activities can arouse student interest in and concentration on science learning. For instance, Fang and Liu (2008) suggest that SM performances captivate students, while also providing them with greater scientific knowledge and an enhanced understanding of scientific concepts.

5E Learning Cycle

Classroom instruction in science education has shifted in the past few decades from a teacher to student-centered approach; concurrently, the practice of scientific inquiry in the classroom has also increased (Bybee 2010). Learning science through inquiry affords students opportunities to form questions and subsequently explore their possible explanations. Hence, inquiry-based learning provides students with occasions to develop and acquire scientific practices and knowledge respectively (Cuevas, Lee, Hart, & Deaktor 2005).

To implement inquiry-based learning efficiently and systematically, Goldman, Radinsky, Tozer, and Wink (2010) advocate the implementation of inquiry cycles. The 5ELC is a popular cycle originally proposed by Bybee and Landes (1988), and its effectiveness as a learning strategy has been documented in numerous studies (e.g., Bybee et al. 2006; Lin & Hsu 2007). In the strategy of 5ELC, each phases stipulate that instructors develop and implement a specific teaching goal in their teaching materials, which are specified below.

To benefit from the 5ELC during the first stage (engagement), it is important to pique student interest and curiosity to ensure their involvement in learning activities, which entails conveying a sense of bewilderment in relation to the observed phenomena (Bybee et al. 2006; Bybee 2009). If students encounter a perplexing situation in the engagement phase that cannot be solved through prior knowledge, they may seek equilibrium in the exploration phase, during which students are allotted sufficient time to explore the objects and situations presented in the learning activities. Based on their prior knowledge, students also utilize the exploration phase to independently develop new concepts and skills.

During the next phase (explanation), students are prompted to formulate an appropriate explanation by discussing the conclusion they reached in the exploration phase with others. The elaboration phase offers students a supplementary opportunity to apply new concepts and skills to unique situations and problems, thus clarifying said concepts and skills. While the final phase (evaluation) does indeed focus on evaluation, self-assessment comprises all five phases: students are repeatedly asked to evaluate their learning, understanding, and skills. Likewise, the teacher also assesses students' learning outcomes.

Numerous studies (e.g., Ajaja & Urhievwejire 2012; Birisci & Metin 2010) indicate that learning activities based on the 5ELC have a positive effect on science learning. Nevertheless, a well-designed activity suitable for inquiry usually contributes to the success of inquiry-based learning (Edelson, Gordin, & Pea 1999). SM performances can generate interest and curiosity in science learning, and its phenomena contradict students' original expectations,

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thereby creating the cognitive disequilibrium typified by the engagement phase. Additionally, SM tricks afford students opportunities to explore scientific concepts and develop thorough explanations. Moreover, when students are challenged to decipher a new, yet similar SM trick, they have an opportunity to apply a previously acquired scientific concept. This research intends to extend the 5ELC's positive effects; accordingly, SM's characteristics are compared with the fundamentals of implementing the 5ELC and devised an innovate approach to integrating it with SM tricks.

Friction Concepts

Friction is a difficult concept for students to acquire because their relevant preexisting ideas concerning it are derived from daily experience. While some of these notions seem to be reasonable explanations of observed ambient phenomena, others are attributable to misunderstandings or incorrect knowledge. Students hold several common misconceptions concerning friction, such as a belief that static objects have no frictional force (Trumper & Gorsky 1997); others assume that because friction causes heat, it is a form of energy rather than force (Kruger, Palacio, & Summer 1992; Osborne, Schollum, & Hill 1981). Learners may also struggle to differentiate between an object's weight and its maximum static frictional force (Osborne, Schollum, & Hill 1981), or face confusion regarding the direction of frictional force (Thijs 1992).

A few studies, however, suggest potentially effective methods for teaching friction-related concepts involving analogical reasoning (Lin & Singh 2011), socio-cognitive teaching (Ravanis, Koliopoulos, & Hadzigeorgious 2004), microscopic explanatory models (Besson & Viennot 2004; Corpuz & Rebello 2011), and hands-on activities (Enyedy, Danish, Delacruz, & Kumar 2012). This research proposes a unique approach involving a series of SM tricks based on the 5ELC to teach friction-related concepts in a conceptually connected and intriguing way, leading to a thorough understanding at the macroscopic level.

Attitudes toward Science

In the past several decades, attitudes toward science have gained an increasingly important role in science education (Craker 2006; Gardner 1975; Ramsden 1998). Gardner (1975) made a clear distinction between attitudes towards science and scientific attitudes, whereby the former encompasses emotional responses related to scientific learning and the latter involves one's willingness to adopt a scientific approach. Moreover, Michaels, Shouse, & Schweingruber (2008) note that attitudes provide a foundation for students to actively and productively learn science in classrooms. This viewpoint is further reflected in the Taiwanese curriculum guidelines for grades 1-9 (Ministry of Education in Taiwan [MET] 2008), which specifically highlight the development of positive attitudes towards science and scientific attitudes in general.

As discussed previously, since SM tricks could be effective activities of inquiry-based learning, teaching materials combining the strategy of 5ELC with SM of a friction unit are developed in this research. Specifically, a series of SM tricks are designed in accordance with the criteria of each phases of 5ELC to teach friction-related concepts. In comparison with the teaching based solely on the 5ELC, the developed materials are taught to eighth-grade students to determine whether integrating SM tricks into the 5ELC could significantly increase the learning outcomes and attitudes toward science of students for a friction unit.

Methodology of Research

A quasi-experimental method is adopted in this research. The participants were divided into experimental and control groups. The experimental group was taught using teaching materials and methods developed using the SM-based 5ELC, while the control group adhered solely to textbook-based materials, which were also based on the 5ELC but did not involve SM activities. For both experimental and control groups, the achievement test of friction unit and the assessment of scientific attitudes were conducted before and after the teaching. Quantitative covariance analyses were then carried out to determine whether there exist significant difference between the experimental and control groups.

Research Sample

Participants of this research were students from two eighth-grade classes at the same junior high school in the central section of Taiwan. Students of this school were of mixed achievement levels upon entering the school during the seventh grade, although their academic performance was later normalized. One class with thirty-seven students comprised the experimental group, which included 19 boys and 18 girls, while another class with 31 students comprised the control group, which included 15 boys and 16 girls. The physical science achievement of the two classes of students was about average for the eighth-grade level of their school.

Teaching Materials and Content for the Control Group

Conceptual content for both experimental and control groups was identical and consisted of: (1) the characteristics of friction, static friction, and kinetic friction; (2) factors influencing maximum static friction (including the relationship between maximum static frictional/normal force and between maximum static frictional force/contact attributes); and (3) friction's influence on daily life. The teaching for the experimental and control groups comprised three lessons, each spanning 45 minutes. Both groups' teaching materials were developed according to the 5ELC, but utilized different activities: while the experimental group employed several magic tricks, the control group adopted examples related to real life experiences. Although different teachers taught the groups, both teachings were adept at guiding students to perform inquiry and proficient in the 5ELC.

The control group's teaching materials included examples from everyday life, and involved activities exploring questions such as why a rolling ball stops after traveling a certain distance, what causes a blackboard eraser to stick to the board after pressure is applied to it, why an empty bookcase can be moved more easily than a full one, and why pushing an object across a rough rather than smooth surface is more difficult.

As the teaching process followed the 5ELC, the teacher initiated the lesson by discussing various life experiences, which were designed to arouse student interest and forge connections between prior knowledge and the learning activities that followed (engagement). Next, these life experiences were used as a foundation for students to explore concepts related to frictional force (exploration). Students were then asked to share the conclusion they reached regarding the problem posed during the exploration phase with others; following this, the teacher introduced and explained relevant scientific concepts to students (explanation). A new life experience was then introduced as students applied their freshly acquired concepts to a unique, yet similar scientific scenario (elaboration).

Teaching Materials and Content for the Experimental Group

As mentioned previously both groups adopted the 5ELC, although the experimental group integrated it with SM-based activities. The following subsections describe some activities in detail.

The striving ring. For this activity (see Figure 1), one skillfully manipulates the frictional and restoring force between a rubber band and ring to maneuver the ring so that it remains stationary, falls down, or moves upward. At the engagement stage, the teacher begins the demonstration with an object hanging onto the tightened rubber band; when the hands are inclined, the object will descend due to the force of gravity. Next, the striving ring trick is performed; as the ring moves upward students' expectations are contradicted, consequently piquing their interest and curiosity. During exploration, students perform the trick independently using a paperclip rather than a ring to explore why the ring stops on the string or moves upward. Finally, at the explanation stage, students are encouraged to discuss their findings and ideas with others, and try to explain the phenomenon behind the trick. After that, the teacher clarifies relevant concepts with formal scientific concepts and definitions.

Figure 1: The striving ring.

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Figure 2: The obedient ball.

Figure 3: Inside the obedient ball.

The obedient ball. Figures 2 and 3 show the obedient ball and its internals respectively. A cotton thread winds around the reel at the ball's center and then exits. When the thread is pulled straightly (but not tightly), the frictional force is reduced. In this state, the ball's gravity is greater than the frictional force, and consequently falls. Comparatively, when the thread is pulled tightly, the static frictional force between the ball and thread will then be equal to the ball's gravity. As a result, the ball stays affixed to the thread, and appears to follow the performer's instructions. Given that students cannot easily discern how the performer pulled the thread (i.e., whether straightly or tightly), conceptual conflict arises. This trick is included in the elaboration stage, and with its introduction, new questions are proposed to determine whether students' conclusions are consistent with the trick's underlying scientific principles. Students are then encouraged to further explore factors that affect friction and the relationship between frictional and normal forces by pulling the thread tightly.

The magical hanging carafe. For this activity one skillfully manipulates the frictional force between a pellet and the mouth of a carafe, as well as a pellet and cotton rope (see Figures 4 and 5). This demonstration should be initiated by showing students that the rope cannot hang from the carafe naturally. Next, the rope must be closely wedged between the pellet and the carafe's mouth; this may require one to place the carafe upside down and pull slightly on the rope. At this point, the rope ought to fully support the carafe as it hangs in the air. This trick should be employed during the elaboration stage, and its introduction prompts students to examine their learning outcomes and propose reasonable explanations after learning about the activity's underlying scientific principles.

Figure 4: The magical hanging carafe.

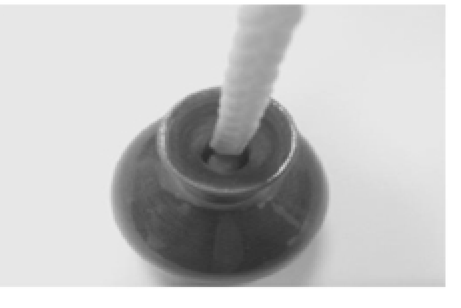

Figure 5: Inside the magical hanging carafe.

More SM-based activities and the relevant designs for the integration of 5ELC were published elsewhere (Lin et al., 2014; Lin et al., 2014).

Measurement Instruments

The measurement instruments implemented in this research comprised an achievement test to evaluate learners' understanding of the friction unit, and an assessment of their scientific attitudes. Learners belonging to both the experimental and control groups completed the achievement test and assessment before and after the teaching occurred.

Achievement test. The achievement test was developed to evaluate students' acquisition of friction-related concepts, and comprised 25 multiple-choice tests. It encompassed concepts related to friction, static/kinetic friction, factors of friction, the relationship between frictional/normal force, and friction's effect on our lives. To ensure that items were properly constructed and relevant to the teaching materials, content validity was established using a two-way specification table in conjunction with input from three experts, including a professor of physics and two experienced junior-high-school teachers. The test's Kuder–Richardson (KR-20) reliability was 0.878 based on 36 students who studied the unit previously.

Assessment of scientific attitudes. Assessment of students' scientific attitudes was conducted in accordance with a scale developed by Lin (2009), which comprised 41 items based on a five-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Likewise, the Cronbach's alpha reliability coefficient (0.868) was based on Lin's study. The instrument included four dimensions: "enjoys inquiry," "takes pleasure in discovery," "careful and precise," and "objective and pursues the final truth"; each of these competence indicators were derived from the Taiwanese curriculum guidelines for grades 1-9 (MET 2008).

The "enjoys inquiry" subscale contained eight items with a coefficient alpha of 0.789, and its content involved the enjoyment of inquiry and discovery, in addition to the enjoyment of practicing scientific ideas through activities or experiments. "I feel that science knowledge learned from a textbook is sufficient, and that there is no need for outdoor observations or experiments" and "When playing with a science toy, I want to understand its underlying mechanisms" are two sample items from the aforementioned subscale. The "takes pleasure in discovery" subscale contained eleven items with a coefficient alpha of 0.804. As for "careful and precise" and "objective and pursues the final truth," these subscales included twelve and ten items with coefficient alphas of 0.767 and 0.763 respectively.

Data Analysis

Quantitative data were analyzed through analysis of covariance (ANCOVA) using SPSS version 17.0. To determine whether the groups were significantly different in their learning achievement, the achievement pre and post-test scores were applied as the covariance and dependent variable respectively, while pedagogy was applied as an independent variable. Furthermore, the pre and post-test science attitude assessment scores were applied as the covariance and dependent variable respectively in order to identify changes in science attitudes between both groups.

Results of Research

The SM-based 5ELC's Effects on Learning Achievement

The mean pre-test achievement scores for the experimental and control groups were 13.05 and 13.93 respectively. For the post-test, the experimental group's mean score was higher (17.76) than the control group's (15.45). Table 1 provides a summary of the means and standard deviations for both groups. ANCOVA of the post-test revealed significant differences between both groups ($F=6.5$, $p<.05$), thus demonstrating that the experimental group (taught using the SM-based 5ELC) achieved superior results.

Table 1. Achievement test means and standard deviations for the experimental and control groups.

Group	Number of students	Pre-test		Post-test	
		Mean	Standard deviation	Mean	Standard deviation
Experimental	37	13.05	4.26	17.76	4.55
Control	31	13.93	4.63	15.45	5.39

*$p<.05$

To determine whether students' conceptual understandings were significantly different for each scientific concept following teaching, the six categories from the achievement test were also analyzed. The means and standard deviations for both groups' pre and post-test scores are shown in Table 2. The analytical results revealed

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no significant differences ($p > 0.05$) in terms of friction [$F = .001$, $p = 0.918$], kinetic friction [$F = .609$, $p = 0.438$], or friction's effect on our lives [$F = .016$, $p = .900$]. On the other hand, significant differences ($p < 0.05$) were present in terms of static friction [$F = 9.768$, $p = .003$], factors of friction [$F = 4.392$, $p = .040$], and the relationship between frictional and normal force [$F = 3.732$, $p = .048$]. Thus, the learning outcome of the experimental group was significantly better than that of the control group in terms of static friction, factors of friction, and the relationship between frictional and normal force.

Table 2. Achievement test means and standard deviations for the six item categories.

Item	Group	Number of Students	Pre-test		Post-test	
			Mean	Standard deviation	Mean	Standard deviation
Friction	Experimental	37	1.08	0.67	1.32	0.70
	Control	31	1.16	0.51	1.32	0.53
Static friction	Experimental	37	4.97	2.34	6.83	2.02
	Control	31	5.09	2.49	5.29	2.47
Kinetic friction	Experimental	37	0.84	0.79	1.49	0.59
	Control	31	0.90	0.64	1.38	0.75
Factors of friction	Experimental	37	1.16	0.91	2.21	0.77
	Control	31	1.25	0.80	1.83	0.91
The relationship between frictional and normal force	Experimental	37	1.67	0.90	2.35	0.84
	Control	31	1.96	0.93	2.00	1.13
Friction's effect on our lives	Experimental	37	3.32	1.23	3.40	1.49
	Control	31	3.54	1.15	3.61	1.55

The SM-Embedded 5ELC's Effects on Science Attitudes

Means and standard deviations of the total scores for the science attitude assessment are provided in Table 3. The experimental group's average pre and post-test scores were 157.73 and 167.54 respectively, while the control group's average pre and post-test scores were 151.52 and 151.32 respectively. Therefore, the experimental group's average science attitude assessment scores were higher than the control group's. However, contrasting the pre and post-test results between the same group reveals that the experimental group's total science attitude assessment score increased following teaching; in contrast, the control group exhibited almost no difference.

Table 3. Science attitude assessment means and standard deviations.

Group	Number of students	Pre-test		Post-test	
		Mean	Standard deviation	Mean	Standard deviation
Experimental	37	157.73	15.365	167.54	15.550
Control	31	151.52	16.868	151.32	15.804

To determine whether the groups' science attitudes were significantly different, an ANCOVA was conducted using pedagogy, the pre-test score, and post-test score as the independent variable, covariance, and dependent variable respectively. The results revealed a significant difference ($F = 24.119$, $p = .000<.001$) between the experimental and control group's science attitudes. This indicates that the experimental group's science attitudes were significantly better than the control group's, who did not adopt the SM-based 5ELC.

Discussion

Enhancements of Learning Outcomes in Friction Unit

This research's intent was to investigate the SM-based 5ELC's impact on science learning. The first research question examined whether there was a significant difference in learning achievement between the experimental and control groups. The results revealed that, following teaching, the experimental group's achievement test scores increased and exceeded the control group's; this indicates that the SM-based 5ELC enhanced students' conceptual understanding of friction. Specifically, students in the experimental group demonstrated a superior understanding of static friction, factors of friction, and the relationship between frictional and normal force. This outcome suggests that the teaching materials and pedagogies built upon the SM-based 5ELC significantly influenced students' comprehension in these three commonly misunderstood areas.

Nevertheless, the experimental group did not show significant improvement in three categories: friction, kinetic friction, and friction's effect on our lives. Regarding friction and its effect on our lives, the scientific concepts embodied in these categories are more concrete; consequently, students already possessed a fairly adequate understanding of them during the pre-test. Furthermore, a shortage of examples concerning friction's effects on everyday life in the teaching materials made it difficult for students to actively solve problems related to this topic. As for kinetic friction, although students were unfamiliar with phenomena involving kinetic frictional force prior to the teaching, its concepts are relatively easy to understand. Thus, this particular result does not indicate significant difference between either groups.

Enhancements of Science Attitudes

The research's second question examined whether a significant difference existed in science attitudes between the experimental and control groups. The findings revealed that the experimental group scored significantly higher, thus indicating that SM used in conjunction with the 5ELC produced results superior to that of the traditional 5ELC alone in this domain.

Lack of student engagement and motivation in practicing scientific inquiry is a known dilemma in science classrooms, which has been documented by Edelson et al. (1999) and Furtak (2006). Furthermore, student attitudes toward science often become negative during secondary school—albeit at a gradual rate (Barmby, Kind, & Jones 2008; George 2000; Potvin & Hasni 2014). SM activities (as form of inquiry-based learning) provide a solution to the aforementioned problems, and enhance pupils' attitudes toward science as they simultaneously acquire new scientific concepts.

Contributions and Teaching Implications

This research proposes an effective approach to integrating SM into the 5ELC, thereby enhancing students' science attitudes and their conceptual understanding of friction. The authors have not only clarified SM's purpose in teaching, but also provided resolutions to problems such as negative student attitudes toward science and disinterest in practicing scientific inquiry. Consistent with Swarat, Ortony, and Revelle (2012), who indicated that various activity types play an important role in determining student' interest, this research suggests that SM activities can effectively contribute to the construction of an interesting learning environment. Moreover, SM should entail more than magic demonstrations. In selecting tricks teachers should be mindful of SM characteristics, and integrate them with the teaching process to ensure effective application. Therefore, additional research is needed to investigate the effects of inquiry-based SM learning activities (covering a variety of scientific topics) on attitudes toward science and student achievement.

Conclusions

In this research, the effects of integrating SM into the 5ELC in a friction unit were investigated. Specifically, thoughtful 5ELC-based teaching materials were developed with SM tricks designed in accordance with the criteria of each phases of 5ELC. A quasi-experimental method was then adopted to explore whether there exist significance differences between the experimental group taught by SM-based 5ELC lessons and the control group taught

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by sole 5ELC ones. It is found in this research that learning effects for the experimental group were significantly higher than the control group, especially in relation to characteristics of static friction, factors that affect friction, and relationships between frictional and normal force. Furthermore, the experimental group showed significant improvements in their attitudes toward science when juxtaposed with the control group. Although the efficacy of SM-based 5ELC lessons was initially examined, additional research covering a variety of scientific topics is suggested to deeper investigate the effects of SM-based inquiry lessons on attitudes toward science and student achievement.

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