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Use of Magic Tricks as Analogies in the Science Classroom

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Abstract: Science, magic, and education have always been linked, from science-based magic shows to teachers presenting demonstrations as magic tricks to capture their students' interest and provide a mnemonic reference for the topics under discussion. Magic as an art form is also often used to convey information or act as an analogy for invisible phenomena. This study examined how the use of a magic effect designed as an analogy for active and passive transport in cells affected student scores and perception of the activity when compared to a standard story analogy in a high school integrated science course. To determine this, students participated in either a magic-based analogy activity (MBAA) or a concrete story-based analogy activity (SBAA), and then data was collected and analysed using a pre-test/post-test for the content and a Likert-scale anonymous survey for the student perception of the activity. The MBAA was shown to be similar to the SBAA in helping students learn but had the added benefit of increasing students' reported engagement with the activity. This study shows how bringing magic into the science classroom can have a positive impact on student engagement and provides teachers with another option to support student learning.

Keywords: *Analogies, magic tricks, science instruction.*

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Introduction

'Science is more than a body of knowledge; it is a way of thinking.' – (Sagan & Druyan, 1997)

While science is both a thought process and a method of understanding the world, it is also a school subject with many processes and concepts for students to understand and memorise. There are numerous topics and areas where students struggle, and finding an interesting way to help all students visualise a concept can be challenging. A common tactic to assist in the transfer of knowledge of science is the use of analogies. Analogies have always been important in the explanation of scientific concepts, and have been used by great science educators to introduce scientific concepts to introductory students and lay people alike (Harrison & Treagust, 2006; Jonāne, 2015). Analogies can be useful especially when a concept is impossible or difficult to visualise (Brown & Salter, 2010).

Often, science teachers will present problems or classroom demonstrations as magic tricks, which are used to capture the students' interest and provide a mnemonic reference for the topic or topics under discussion. The first phase of the 5E Instructional Model (a common and effective science teaching strategy) is 'Engage,' of which the main purpose is to pique students' interest to begin the learning process (Hoover, 2016; Lin et al., 2014). Sometimes, the engage phase is a demonstration of scientific phenomena, and could very easily appear to be a magic trick. In the nineteenth century, public lectures became the fad of the time, and the most popular of which were those about science as they often showed 'dramatic experiments' (Scott, 1980, p. 803), which may have felt like watching a magic show. The connection between magic and science is ubiquitous, so an investigation into the use of magic tricks as analogies for science concepts can logically be designed.

The purpose of this study was to determine if a magic effect used as an analogy would be useful in helping students understand and remember difficult to visualise concepts, specifically active and passive transport in the cell. Additionally, this study investigated how the use of a magic analogy impacted student engagement with the lesson. This could provide

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science teachers with another method for teaching difficult concepts while also increasing student engagement and enjoyment of those lessons.

Literature Review

Student Understanding of Cell Transport

Several studies have explored students understanding of cell biology, specifically in undergraduate students (e.g., Fisher et al., 2011; Suwono et al., 2021). Amongst other topics (i.e. cell development) students have been shown to have difficulties understanding transport across the cell membrane (Suwono et al., 2021). Fisher et al. mention student difficulties in these topics likely result in part because it involves small particles moving, so they can't be observed, along with often being taught in a traditional lecture-style which makes it difficult for students to connect to the material (2011). Walton (2023) demonstrated that student-generated drawings of cell membranes helped improve student understanding of transport likely because it helped students make their mental models more visible to them and the instructors in order to help address misconceptions directly.

Magic in the Classroom

There has always been a connection between the sciences and magic. The classic example is alchemy, but many science classroom demonstrations can appear to look like magic as well. The fact that some chemistry looks like magic has been used by educators to produce chemistry or science magic shows to help boost interest and enthusiasm for the subject (Fenster et al., 1985; Lin et al., 2014), and has also been used to assess student learning by having students perform science-based magic shows (Duthie-Fox, 1999). Alternatively, magic can be used as a jumping-off point for an inquiry lesson, asking students to observe and reflect on what they see and explain it using a scientific concept (Lin et al., 2014, 2017; Taufiq et al., 2017). Additionally, having students perform magic in a classroom setting shows students that they can achieve mastery through practice, build their self-esteem, enhance their creativity, and help develop team spirit in the classroom (Broome, 1995). It is suggested that having students watch and learn how to perform magic effects can also boost student divergent thinking (Wiseman et al., 2021).

One common use of magic in the science classroom is as a presentational hook because magic is inherently attention-grabbing. Magic as an art form can 'disrupt and subvert an audience's sense of reality, and in some cases, their fundamental set of beliefs about how the world "works"' (Landman, 2018, p. 4). This means that magic is inherently jarring, so it works like a discrepant event (Weaver, 2008), which has been shown to enhance student learning or begin a lesson as the engage portion of the 5E Instructional Model (Lin et al., 2014). In classroom settings, teachers who also happen to be magicians (or magicians who also happen to be teachers) have qualitatively observed that magic tricks done in front of a class capture student attention and causes students to focus closely on what is being presented due to their surprising nature (Domínguez, 2013/2020; Kett, 2002). Jeffrey Hepburn, a US award-winning high school chemistry teacher, used magic in his classroom to assist with inquiry and as diversions from the usual curriculum to make sure students continue thinking even while taking a break from content (Hepburn & Jacobsen, 2010).

Magic is also a useful medium for presenting information or emphasising a point. Landman (2018) uses his magic show to communicate ideas about philosophy, science, and other ways we know what we know about the world by weaving lessons and stories into his presentations. Another example of this is the first author's own magic shows where he discusses electron quantum tunnelling and the Heisenberg uncertainty principle while a sponge ball vanishes from one hand and reappears in the other. While the sponge balls are not actually moving due to quantum tunnelling, the explanations are scientifically accurate *and* entertaining to the audience (anecdotally assessed based on applause and laughter).

Magic and Learning

A common practice in the science classroom is to use discrepant events to introduce a topic. A discrepant event is 'an experience that is overtly counterintuitive and directly challenges students' held conceptions' (Weaver, 2008, p. 40). Discrepant events work particularly well as the engage portion of the 5E Instructional Model as they often appear to defy the laws of nature (Hoover, 2016). Discrepant events are often used in science classrooms because research has shown that they lead to conceptual change and increase student motivation (González-Espada et al., 2010; Madden et al., 2016; Weaver, 2008). Additionally, when presenting discrepant events, teachers will sometimes act as magicians, setting up students to expect one outcome and surprising them with observations that are unexpected (González-Espada et al., 2010).

In addition to being a discrepant event, magic can be used as an analogy in the classroom. The usefulness of analogies in the science classroom has been studied extensively, with teachers and researchers discussing which kinds of analogies work best and how to use them to teach science content effectively (Aragón et al., 2014; Brown & Salter, 2010; Glynn, 2012; Sahidu et al., 2021; Shana & Shareef, 2022; Treagust et al., 1996; Tsai, 1999). Like discrepant events, analogies have been shown to support conceptual change in students (Treagust et al., 1996). Analogies help students learn by providing identifying similarities between something familiar or known to the student and the concept or idea being learned; they prompt students to connect learning to their prior knowledge (Glynn, 2012). The more similar the shared features the better the analogy as a learning tool. When students generate the analogies, they can be a better learning tool since the students actively connect the target material to concepts they already know, while teacher-generated analogies might assume student understanding of the analogue concept (Aragón et al., 2014). Analogies that are student-generated can also be useful as methods of assessment to evaluate understanding (Lancor, 2014). Along with benefits for learning, analogies also have problems as they can lead to misunderstandings when it 'is difficult to map the important features shared by the analogue and the target' or when students are unfamiliar with the analogue (Glynn, 2012, p. 226). It has been observed that teachers often use analogies extemporaneously as opposed to drawing on those that are specific and thoughtful (Harrison & Treagust, 2006; Shana & Shareef, 2022; Treagust et al., 1992). However, these drawbacks can be mitigated if time is dedicated to looking not only at how the analogy works well, but also where it breaks down (Treagust et al., 1998). Additionally, there are those who affirm that any sort of mnemonic devices or 'memory tricks' in the classroom are useful for students, especially those who may not be particularly interested in the subject matter initially (Seiler & Huggins, 2018; West, 2014). Minding these cautions for analogies, magic tricks which students experience may provide effective teacher-directed analogies for students. When the trick is performed in class, the teacher does not have to assume student prior knowledge for the analogue, rather the trick provides students with a common analogue so all involved can make explicit connections between the trick and the target concept. To date though, there is no research exploring this type of analogy or use of magic.

There is a place for magic in the science classroom based on the inherent connection between magic and science, the use of magic as an attention-grabbing theme, and magic tricks' usefulness for delivering information as discrepant events and/or analogies, but the use of magic tricks acting as effective analogies in the science classroom are missing from the literature. Specifically, Wiseman and Watt (2020, p. 6) recommend "testing the efficacy of magic tricks that are specifically designed to deliver educational messaging". They continue:

> This work could be experimental in nature, comparing the impact of different types of illusions and presentations with other techniques designed to enhance curiosity and retention. Researchers could also examine how magic-based interventions affect the understanding and recall of material that is both related to the intervention or presented subsequently (Wiseman & Watt, 2020, p. 6).

Wiseman et al. (2020) followed up by performing their own study based on the above suggestions, specifically to deliver information about the Apollo Moon landings. While their study used a series of magic effects to deliver a set of facts, the magic itself was not part of the information. Their study also used videos to deliver the messaging as opposed to an in-person classroom. The following study investigated the use of a magic effect specifically designed as an analogy to reinforce and recall the concepts of cellular active and passive transport (CAPT) in an in-person science classroom setting.

Problem Statement and Research Questions

Even though there has been a shift in the way science is taught to a more inquiry-based method, there is still an abundance of knowledge that is required to be memorised or concepts to be understood. This is especially true in advanced secondary courses such as those in the Advanced Placement (AP) or International Baccalaureate (IB) programs. Finding mnemonics, analogies, or additional ways to help students understand concepts, especially those that help students visualise what is happening at the microscopic level, is useful for any science classroom. Teachers often use analogies to help transfer scientific information, and students sometimes require analogies or visualisations to represent challenging microscopic phenomena (Jonāne, 2015). Additionally, it is important to engage students to begin the learning process (Hoover, 2016; Lin et al., 2014). This study attempted to use a magic effect to engage students and help them remember and visualise CAPT concepts, which can be difficult to visualise on a microscopic level. It was guided by the following research questions:

RQ1: How does a magic-based analogy activity (MBAA) affect student learning and recall of CAPT concepts as measured by a written assessment when compared to a story-based analogy activity (SBAA)?

RQ2: Is there a difference in student perception of the analogy activity based on participation in the MBAA versus the SBAA?

Methodology

To determine the effectiveness of the magic-based analogy activity (MBAA) for student learning (RQ1), a convenience sample of students was used, and a pre-test/post-test score analysis was completed. To determine the student perception of the activity (RQ2), the students took a survey about the analogy activity when it was completed.

The design of this experiment had all participants performing an analogy analysis activity, but one group completed it with a magic trick at the centre while the other looked at a standard analogy, a story-based analogy activity (SBAA). This design should demonstrate if there is a difference in retention of the content based on the analogy activity in which the students participated. Additionally, a questionnaire survey was given to reveal what students thought about the MBAA and the SBAA and would provide additional insight that could not be seen in the quantitative assessment analysis.

Research Participants

A convivence sample of students in the first author's classes and in the other sections of the same course at his school were used for this study as they were available to the author. The students who experienced the MBAA (the experimental group) were in the first author's two sections of Integrated Science (IS) plus two additional sections regularly taught by other teachers and taught at times when the first author was not teaching to "perform" the trick; the control group (those who experienced the SBAA) consisted of students in the other three sections of IS not taught or visited by the author. All sections of IS offered at the school are represented in this study.

At the school where the study took place, IS is a two-year mixed-age course that goes through the basics of US high-school biology, chemistry, physics, and environmental science in an integrated way. Students take IS during their ninth and tenth grade years (14–16 year-olds). The three teachers of IS meet regularly and teach the same lessons at the same pace. Therefore, the students in IS represent all ninth and tenth-grade students at the high school, and as such, the study consisted of those ninth and tenth-grade students. The sections of IS are not organised or grouped based on grade, student ability, or any other factor besides scheduling – the classes were truly mixed. Also, the fact the teachers all teach the same content at the same pace acted as an additional level of control. The section receiving the treatment, MBAA, was chosen based on the first author's ability to perform the trick in their class (either his own or another section when he was not teaching). The population of the school is majority White students, with 32% of the student body identifying as students of colour, and with 25% of students in the school receiving some form of financial aid, which is similar to other non-profit private schools in the region (National Association of Independent Schools, 2020).

MBAA and SBAA Design

The magic trick used in this study for the MBAA was a card effect created by the first author[i] where the diamonds on a standard playing card jump from card to card such that they move from high-to-low concentration or vice-versa. For example, at one point in the routine, a Ten of Diamonds and a blank card became two Five of Diamonds when put together in order to 'equalise the concentration of diamonds' on the two cards. For an additional surprise, toward the end of the trick, a Ten and a Five of Diamonds combine together using additional energy (active transport) to create a single novelty Fifteen of Diamonds card. The trick ends with the Fifteen of Diamonds 'diffusing' onto two other blank cards to form three Five of Diamonds cards again (Rudnick, 2021).

Students in the control group (SBAA) were given an analogy about people on a subway train moving from areas of high to low concentration and then discussed how it related to the terms learned in class. Specifically, students were asked to visualise the Addison Red Line 'L' stop in Chicago (which is right next to Wrigley Field) on the day of a Chicago Cubs baseball game as people exit and enter the crowded train before and after the game. The school where the study took place is in a large metropolitan area, and many students commute via the public transit system, so this analogy was particularly relevant to this group of students.

Research Design

In the study, all students were given the pre-test in the form of a 20-item paper-based multiple-choice and fill-in-the-blank style exam written by the author of this paper with questions from and inspired by Lang (n.d.) and Lyons (S. Lyons, personal communication, September 16, 2021). Students were given this test by their usual teacher at the beginning of class and told to try their best even though they were unfamiliar with the topics assessed, and were given approximately 20 minutes to complete the test. After the pre-test, all students received the same lessons related to CAPT concepts, like concentration gradient and diffusion, and were introduced to the terms hypotonic, hypertonic, isotonic, and active and passive transport. These lessons took the form of in-class lectures with guided notes and Process Oriented Guided Inquiry Learning (POGIL) activities (Trout, 2012). During one of the classes, all students participated in an analogy analysis activity. As stated above, students in the experimental group examined the card trick while students in the control group examined the train analogy. For both groups, the students were given a worksheet to relate aspects of the magic trick or story to the terms learned during lectures and activities (See Appendix A – both versions). The students first worked individually, then in small groups, then discussed their ideas as a whole class. The next class meeting after the activity, the students were given the post-test, which was the same exam as the pre-test, using the same general procedure as the pre-test. The post-test was not announced beforehand so students would show what they remembered from the previous lessons without studying or additional self-practice. Students were also asked not to tell students in other classes about the unannounced post-test. All students in the classes were given the pre and post-test and participated in the analogy activity if they were present, but only scores from students who returned consent forms and were in class on the day of the analogy activity were analysed. The resulting sample then was N=36 for the MBAA group, and N=27 for the SBAA group.

Once the post-test was graded and returned with feedback, students in all classes were given an anonymous questionnaire about the analogy activity in which they participated (Appendix B). The first part of the survey contained 5-point Likert scale questions created by the first author about whether they believed the activity helped them with the content and whether they found the activity useful and/or enjoyable. The second part had students choose words from a list (with the option to write in their own words) to represent their thoughts about the analogy activity. Finally, in the third part, students who did the SBAA were asked about a hypothetical MBAA, while the converse was asked of students who did the MBAA. Students were also allowed to add their own additional comments in the third section. Some students left a full response in the fill-in-the-blank word question instead of in the last question of the survey, so a full response in that question was analyzed as a response to the final open-ended question. Besides this last section on the survey, students were not specifically told that some classes saw a magic trick while others did not. Since the survey was anonymous and delivered via Google Forms, it was not possible to remove students' responses who did not consent to the exam score collection, though they were told not to complete the survey (but sent to computers so as not to publicly identify those who did and did not consent). This resulted in a slightly larger sample of participants for the survey data: N= 40 MBAA, and N= 30 SBAA. Since there is similar distribution to the exam data, and the data from the survey sought student opinions, it was concluded that the difference in sample size was acceptable as students were not lost, just merely could not identify which had not consented to the use of their exam scores in the study.

Students' scores on the assessments were collected and compared statistically using both paired and independent sample t-tests to determine whether learning occurred (paired-sample) and to determine if the scores between the groups were statistically different (independent-sample). The 5-point Likert-style questions on the post-test were analysed by converting the responses to numbers to allow the mean and standard deviation to be calculated. A response of 'strongly disagree' was considered '1' while a response of 'strongly agree' was considered '5,' with the other responses representing whole numbers between. These numbers were compared using a two-tailed equal variance t-test with an alpha of .05. The use of a t-test for 5-point Likert-style tests has been shown to be a useful method of analysis, as described by de Winter and Dodou (2019). Additionally, descriptive statistics were used for some survey questions, and the open-ended question was read by the first author for common themes, phrases, or descriptions to qualitatively determine why students may have responded the way they did on the rest of the survey.

Results

For the pre-test and post-test, the students whose data was analysed were those who met all of the following four pieces of criteria: they returned their consent and assent forms, they completed the pre-test before any lessons were given, they were present in class for the analogy activity, and they completed the unannounced post-test during the class immediately following the analogy activity. The classroom distribution and the above criteria resulted in a sample size of 36 students in the MBAA group and 27 students in the SBAA group.

Student pre-tests and post-tests were analysed using a paired t-test to determine learning, and an independent sample t-test to determine if the difference in the scores between the groups was statistically significant. An alpha level of .05 was used for all t-tests. Both groups saw a significant increase in their scores from the pre-test to the post-test, indicating that learning was achieved for both groups (Table 1). With 20 points possible on the tests, the MBAA group increased from an average of 6.47 (SD = 3.54) on the pre-test to an average of 16.15 (SD = 3.41) on the post-test, t(35) = 15.42, $p <<$ .001. The SBAA group tests increased from an average of 7.78 (SD = 3.31) to an average of 15.04 (SD = 4.27), t(26) = 9.05, $p <<$ .001.

Table 1. Pre-test/Post-test Score Analysis

Group			**Pre-test**		**Post-test**		**Change**	
	N		**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
MBAA	36		6.47	3.54	16.15	3.41	9.68	3.77
SBAA	27		7.78	3.31	15.04	4.27	7.26	4.17

t-test pre to post			**t-test comparisons**		
	MBAA	**SBAA**	**Pre-test**	**Post-test**	**Change**
t-statistic	15.42	9.05	1.44	1.15	2.41
p	<<0.001	<<0.001	0.15	0.25	0.02

Comparing the change in scores from the pre-test to the post-test for the two groups shows a statistically significant difference with the MBAA having a greater increase in scores (M = +9.68, SD = 3.77) than the SBAA (M = +7.26, SD = 4.17), t(61) = 2.41, p = .02. However, when only the pre-test and post-test scores are compared, a t-test shows that there is no statistically significant difference between the groups (pre-test: t(61) = 1.44, p = .15; post-test: t(61) = 1.15, p = .25) (also in Table 1).

The second portion of the experiment was the survey after the post-test. Students were told to only take the survey if they participated in the analogy activity. Since the survey was completely anonymous and distributed via Google Forms, some students whose test scores were not analysed took the activity survey. After the surveys were collected, there were 40 student responses in the MBAA group and 30 student responses in the SBAA group. Most questions were answered by all students, but not all questions were answered. Some of the questions showed a statistically significant difference in the responses between the two groups (Table 2), though a majority of questions did not (Table 3).

Table 2. Questions w/ Statistically Significant Differences in Responses

	MBAA N=40		SBAA N=30				
	Avg	**SD**	**Avg**	**SD**	**df**	**t-stat**	**p-value**
The analogy activity helped increase my understanding of… … diffusion	3.75	0.81	3.20	1.06	68	2.46	0.016
The analogy activity was enjoyable	4.20	0.56	3.55	0.74	67	4.14	<0.001
The analogy activity was engaging	4.20	0.72	3.60	0.81	68	3.26	0.002
The analogy activity was boring (negative question)	1.93	0.69	2.60	1.04	68	3.26	0.002

The first few questions asked students to agree or disagree with statements asking if the analogy activity helped them with different CAPT concepts such as concentration gradient, diffusion, active transport, and passive transport. Only the question about diffusion showed a statistical difference, with students in the MBAA group (M = 3.75, SD = .81) agreeing with the statement more than the students in the SBAA group, (M = 3.20, SD = 1.06), t(68) = 2.46, p = .02.

Students were also asked multiple questions about whether they enjoyed the activity, thought it was engaging, or found it boring. For all three of these questions, students in the MBAA responded by agreeing more with the positively worded questions (engaging and enjoyable) and disagreeing more with the negatively worded question (boring) than students in the SBAA (see Table 2).

As previously mentioned, most questions showed no statistically significant difference between the groups (see Table 3), but the student answers are still important for analysis. For the question asking if students understood the purpose of the activity, both the averages in the MBAA (M = 4.10, SD = .55) and SBAA (M = 4.20, SD = 0.61) were heavily in the agree range. For the question about whether the students felt the activity helped them perform better on the post-test, the average MBAA response (M = 3.23, SD = .89) and SBAA response (M = 3.50, SD = .82) are in the neither agree nor disagree range, but slightly skewed toward the agree side. Similarly, another question phrased in the negative ('This activity did not help me at all') was also in the middle range but skewed toward disagree for both the MBAA (M = 2.45, SD = .88) and the SBAA students (M = 2.27, SD = .78).

Table 3. Questions w/ No Statistically Significant Difference in Responses

	MBAA N=40		SBAA N=30				
	Avg	**SD**	**Avg**	**SD**	**df**	**t-stat**	**p-value**
The analogy activity helped increase my understanding of … concentration	3.78	0.77	3.83	1.05	68	0.27	0.79
… passive transport	3.45	0.88	3.57	0.73	68	0.59	0.56
… active transport	3.80	0.76	3.83	0.79	68	0.18	0.86
… concentration gradient	3.33	0.83	3.50	1.01	68	0.80	0.43
The analogy activity helped me do better on the posttest	3.23	0.89	3.50	0.82	68	1.32	0.19
I understood the purpose of the analogy activity	4.10	0.55	4.20	0.61	68	0.72	0.47
The analogy activity did not help me at all (negative question)	2.45	0.88	2.27	0.78	68	0.91	0.37

Additionally, one question asked students whether they would like to do this activity again with another topic in the future (options were yes, maybe, and no). Overall, a majority of students said they would like to do the activity again in both groups. 52% of students in the MBAA group (21) said yes to doing the activity again, while 43.3% of students in the SBAA group (13) said yes. Additionally, only 4 students total (2 in each group) answered 'no' to this question. A chi-squared analysis of this data showed no statistical significance to the difference between the groups, X^2 (2, N = 70) = .59, p = .74.

Finally, there were two questions where students could give their own responses. One question asked students to choose three words or phrases from a list that describe the analogy activity (See Appendix B for the question), though they also had the option to write in their own word. The biggest differences between the two groups were for the words 'fun,' 'useful,' and 'boring.' For the word 'fun,' the MBAA group had 78% of respondents picking it, while only 23% of SBAA students picked it; for the word 'useful,' the MBAA group had 33% of respondents picking it, while 60% of SBAA students picked it, and finally only 1 student (3%) of the MBAA group picked 'boring' while 5 students (17%) of the SBAA group picked it. Additionally, students in both groups wrote in the word 'confusing,' however 2 students did in the MBAA group while only 1 student did in the SBAA group (Table 4).

Table 4. Word Choices and Responses

	MBAA		SBAA	
	N	%	N	%
Fun	31	78%	7	23%
Useful	13	33%	18	60%
Boring	1	3%	5	17%
Informative	22	55%	19	63%
Helpful	18	45%	13	43%
Waste of Time	0	0%	0	0%
Easy	4	10%	6	20%
Challenging	3	8%	2	7%
Neutral	18	45%	14	47%
Engaging*	1	3%	0	0%
Confusing*	2	5%	1	3%
Didn't really use it*	1	3%	0	0%
Impressive*	1	3%	0	0%
TOTAL RESPONDENTS	40	100%	30	100%

* Student entered words

The students also responded to a question that asked, 'Would you like to add any additional comments in regards to the analogy activity?' Most students either left it blank or responded with a variation of, 'nope.' A few students in the MBAA group said statements about how they thought the trick was cool, helpful, fun, and informative. One student said they were more focused on how the trick was done. One student specifically said the MBAA 'helped me retain the information because it was visual and engaging.' One respondent in the MBAA group said, 'It was really cool that you used other forms of teaching unlike other classes.' Some students in the MBAA group thought that the activity was only useful because we learned the material first, with one student saying, 'If we would have done this activity without learning about this topic prior, I do not think I would learn from it,' and another student responding similarly, saying, '… I felt we already covered the info enough to understand it without the analogy.' Students in the SBAA group mostly left this additional question blank or said, 'no,' though one student said that seeing something visual is nice, but any old descriptive pictures/analogy would do the same thing. Another student said that the SBAA was confusing for specific CAPT concepts, but this student's response had many typos, so it was hard to discern specifically which CAPT concepts were confusing in the story for this student.

Discussion

RQ1: Student Learning

The first part of the experiment was to investigate if the MBAA affects student understanding and recall of CAPT concepts compared to the SBAA. Pre/post-tests showed both groups had significant learning, and there was found to be no statistical difference between the post-test scores of the two groups. Similar to previous research on analogies (Aragón et al., 2014; Treagust et al., 1996), both activities appeared to support student learning on the difficult topic of cell transport (Suwono et al., 2021). While there was a statistical difference between the change in scores from the pre-test to the post-test, indicating the MBAA caused student scores to increase more than the SBAA, it could be misleading. The group for the MBAA was larger, and while the t-test showed that there was no statistical difference between the averages of the pre-test scores and post-test scores between the groups, the average pre-test scores were lower, and average post-test scores were higher for the MBAA group, which could have led to the statistical difference of the score increase. This could be because the MBAA group was larger but still rather small (i.e., less than 50). Thus, a few extreme scores can impact data to a greater degree. Since the post-test scores of the two groups were not statistically different, it can be concluded that students in both groups learned the content, and the MBAA inclusion as a learning tool did not significantly increase or decrease student learning as the choice of analogy.

These findings suggest that the magic trick provided some of the needed components for successful analogies. With no difference in the MBAA group and SBAA group, the analogue features connecting the target concept of transport to the analogues of both the trick or the commute must have been similar in number and in similarities to the concept, as is needed for a successful analogy (Glynn, 2012). In addition, with similar results and the thoughtful use of both activities by the teachers, it appears that the students did not think the MBAA or SBAA were extemporaneous, which is a common problem for analogy use (Harrison & Treagust, 2006; Shana & Shareef, 2022; Treagust et al., 1992). The success of the magic trick as an analogy might also relate to the improved success that student-generated analogies can have (Aragón et al., 2014). While the instructor did provide the structure for the magic trick, all of the students experienced it together, knowing that it was being used to help them learn the concept, so it might have improved their understanding. The student survey results discussed below provide evidence for this as well.

RQ2: Student Attitudes towards Analogy

The second area of investigation was whether the activity type affected student perception of the analogy activity. While most questions answered on the survey were not statistically different between the two groups, those regarding student engagement and enjoyment were, with students finding the MBAA more enjoyable, more engaging, and less boring than the SBAA. This is similar to other studies that showed students who participated in magic-based activities saw a marked increase in their attitudes toward science and engagement with the material (Lin et al., 2014, 2017), and found the magic version of the lessons were more entertaining than the non-magic ones (Wiseman et al., 2020).

Students self-reported for both activities that they thought the activity somewhat helped with their post-test scores, and a significant majority of students for both activities answered yes or maybe to doing this activity again for another topic. Additionally, similar numbers of students responded that they understood the purpose of the activity and found the activity helpful, while no students chose the phrase 'waste of time' for either activity in the word choice question, meaning both activities were found to be beneficial in some way according to the students. This agrees with other studies about analogy-based activities (Shana & Shareef, 2022; Treagust et al., 1996).

Based on the word choices, more students said that the MBAA was fun (as supported by other questions), but more students said the SBAA was 'useful' and 'informative.' One possible reason for this is that the SBAA made use of a concrete occurrence that is quite familiar to the students. Since the school is in the Chicagoland area, and many students commute to the school, they are accustomed to trains and public transportation, making the analogy of people entering and exiting a train something they have experienced in their everyday lives. The MBAA used abstract diamonds on playing cards to represent solutes, so students may have had a harder time connecting with the analogy. This could explain why 2 students said the MBAA was 'confusing,' while only 1 student said the SBAA was. This can also be seen in the questions regarding how the activity affected student understanding of different CAPT concepts. Except for 'diffusion,' the averages for the SBAA were higher than the MBAA for all specific concepts, though not higher in a statistically significant way. This could be that the SBAA used concrete images to portray CAPT concepts, such as the doors of the train representing membrane-spanning channel proteins, while the MBAA focused more on the idea of diffusion and had no specific mentions of those proteins for facilitated diffusion or active transport. This is similar to the findings of Lin et al. (2017), which showed that students' conceptual understandings of some areas of physics were improved by the magic activity in their study, while other real-world applications were not improved since the concrete applications were not specifically discussed as much with the science magic group. However, for the MBAA and SBAA in this study, students were asked to identify CAPT concepts that were not present or well defined in the presented analogy, so both groups had chances to discuss all CAPT concepts during their particular activity. This was an intentional design in this activity and experiment, as it has been established that both the usefulness and limitations of an analogy should be discussed when analogies are utilised during a lesson (Harrison & Treagust, 2006; Niebert et al., 2012; Treagust et al., 1992, 1998).

With the lack of literature on the use of magic acting as an analogy for educational purposes, this study contributes to the existing literature on the use of magic to deliver educational messaging. The MBAA was created by a practicing magician and veteran teacher (the first author), and while the results partly relied on student self-reported engagement, it also made use of a control group (the SBAA) and used student assessment scores to evaluate learning, all of which are specifically recommended for future studies of magic-based educational interventions by Wiseman and Watt (2020). The results of this study have provided evidence for the continued use of magic in the classroom along with some recommendations, below, for its use and continued study.

Conclusion

The MBAA and the SBAA both affected student scores on the post-tests equally, and students found both activities useful and helpful, though students found the MBAA more engaging than the SBAA. This very well could be because magic itself is engaging and enticing, as one coworker of the first author stated, 'I wish all important information was presented in the form of close-up magic.' While there were limitations to this study, neither activity was shown to negatively impact the students, and no students considered either activity a waste of time. Based on the data and survey responses, a magic effect designed as an analogy to enhance student understanding was shown to be similar to concrete analogies in helping students learn but had the added benefit of increasing student reported engagement with activity.

Does this research imply that all teachers should incorporate magic into their classrooms? Not necessarily, but they could if they want to as a successful analogy. Magic happens to be the first author's hobby and passion since childhood, so he wanted to see if bringing magic into his classroom would help students learn science content. Future studies could investigate how an individual teacher's passion incorporated into a lesson would affect student understanding, retention, and engagement as well. Teachers are encouraged to bring their passions and hobbies into their classrooms as it can increase engagement and foster relationships with the students, along with showing students that learning anything (not just school subjects) can be fun and rewarding (Ham, 2021). This study demonstrated that magic could be used to help students learn and review material at least as well as a concrete analogy, so students in the first author's classes will continue to see magic during instruction, and he will qualitatively test these demonstrations for their effectiveness for the rest of his career.

Recommendations

Magic has demonstrated promise as an analogy and a useful tool for the science classroom. As described above, educators should treat magic with many of the same recommendations for analogy use in the classroom. They are tools, but not the only ones, and they need to be used properly. Teachers should practice the tricks first and perform one that they can skillfully use, not just depend on a teacher who has been practicing magic for over 30 years. For future research, it would be useful to have a true control group that did not participate in any analogy activity or to design comparable magic and story analogy activities that are used specifically to deliver the content initially, similar to the Wiseman et al. (2020) study. Lin et al. (2017) also noticed that some content knowledge was high for both groups before and after the activities, so participation in magic activities did not affect student performance in those specific content areas. It is important for the students to be familiar with the concrete analogy scenario or to have high levels of abstract and imaginative thinking to make the analogy particularly effective (Harrison & Treagust, 1993, 2006; Lancor, 2014; Niebert et al., 2012; Seiler & Huggins, 2018; Shana & Shareef, 2022; Treagust et al., 1998). Future experiments would benefit from having comparable MBAA and SBAA scenarios that are either both similarly abstract or similarly concrete for more accurate comparison purposes.

Limitations

One major limitation with the above data was described by two students in their free response survey questions: It was stated that those students felt they had learned enough content to perform well on the post-test without the analogy activity. This particular analogy analysis activity was designed as a review of the content, so it is possible that neither the MBAA nor the SBAA had a significant effect on student learning, though some students self-reported that it did support their learning.

Another limitation, as discussed previously, was that the SBAA was about a concrete circumstance that the students in this study experienced on a daily basis, while the MBAA was more abstract. This could have affected students' understanding of the material, though the data showed that students in both groups understood the material by the time the post-test was given.

Finally, the first author of this paper only performed the MBAA in his classes. The other teachers conducted both the MBAA and SBAA in their sections but were visited by the author to conduct the MBAA. This could have added additional novelty to the MBAAs in those groups by having a different-than-usual teacher lead a lesson for the class, possibly increasing the 'engagement' scores for the MBAA. It also would have been prudent to have the author of the study conduct at least one SBAA section. It is unknown how having the author perform both activities would have affected the results, but since the author was the only one who could perform the card trick, it made the most sense to have him do that as much as possible during the study.

Ethics Statements

Institutional Review Board (IRB) at Illinois State University was obtained for the work reported here, number: IRB-2021-300.

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Appendix A: Analogy Analysis Activity Worksheets

Magic Analogy Analysis Activity **NAME: ___________________**

Cellular transport is like the 5 of Diamonds card trick:

1. A packet of 5s can be kept together because the diamonds are evenly distributed.
2. With energy, two 5s can combine to become 10s, but would prefer to be distributed as two 5s
3. With extra energy, a 10 and a 5 can combine to make a 15
4. 15 and two blanks will become three 5s when put together

Based on the analogy, what part or parts represent:

- Solute
  -
- An area of high concentration
  -
- An area of low concentration
  -
- Diffusion
  -
- Facilitated diffusion
  -
- Active transport
  -
- Cell membrane
  -
- Membrane spanning protein
  -

Give an example from the analogy using the terms hypotonic, hypertonic, and isotonic.

For the parts that did not fit into the analogy, describe how to make them fit, or explain why they don't fit.

What could you add to the analogy to explain one of the parts that doesn't fit?

CTA Analogy Analysis Activity **NAME: ___________________**

Cellular transport is like being at the Addison stop on the red line:

1. Before the game, a crowded train pulls up, the doors open and a bunch of people exit from the crowded train onto the empty platform.
2. After the game, a train pulls up and the people on the crowded platform enter the train through the doors.
3. At some point, there are too many people on the train, but people push on anyway.

Based on the analogy, what part or parts represent:

- Solute
  -
- An area of high concentration
  -
- An area of low concentration
  -
- Diffusion
  -
- Facilitated diffusion
  -
- Active transport
  -
- Cell membrane
  -
- Membrane spanning protein
  -

Give an example from the analogy using the terms hypotonic, hypertonic, and isotonic.

For the parts that did not fit into the analogy, describe how to make them fit, or explain why they don't fit.

What could you add to the analogy to explain one of the parts that doesn't fit?

Appendix B: Survey

Post Analogy Lesson Survey

Please fill out this survey after you have completed your analogy activity AND your posttest. This survey is anonymous. You may answer as many or as few questions as you like, but you must answer the first question for data sorting purposes.

* Required

1. Which analogy activity did you do in class? *

Mark only one oval.

- ◯ The Subway Train Car *Skip to question 6*
- ◯ The Card Trick *Skip to question 7*

2. For each of the following statements, choose whether you agree or disagree.

Mark only one oval per row.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
The analogy activity helped increase my understanding of CONCENTRATION.	◯	◯	◯	◯	◯
The analogy activity helped increase my understanding of DIFFUSION.	◯	◯	◯	◯	◯
The analogy activity helped increase my understanding of PASSIVE TRANSPORT.	◯	◯	◯	◯	◯
The analogy activity helped increase my understanding of ACTIVE TRANSPORT.	◯	◯	◯	◯	◯
The analogy activity helped increase my understanding of CONCENTRATION GRADIENT.	◯	◯	◯	◯	◯

3. For each of the following statements, choose whether you agree or disagree.

Mark only one oval per row.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
The analogy activity did not help me at all.	⬭	⬭	⬭	⬭	⬭
The analogy activity was boring.	⬭	⬭	⬭	⬭	⬭
The analogy activity helped me do better on the posttest.	⬭	⬭	⬭	⬭	⬭
The analogy activity was enjoyable.	⬭	⬭	⬭	⬭	⬭
The analogy activity was engaging.	⬭	⬭	⬭	⬭	⬭
I understood the purpose of the analogy activity.	⬭	⬭	⬭	⬭	⬭

4. Pick up to three (3) words or phrases that you feel describe the analogy activity. You may also write in your own word or words

Check all that apply.

- ☐ Fun
- ☐ Useful
- ☐ Boring
- ☐ Informative
- ☐ Helpful
- ☐ Waste of time
- ☐ Easy
- ☐ Challenging
- ☐ Neutral (neither bad nor good)

Other: ☐ ______________________

5. I would like to do this analogy activity again with another topic in the future.

Mark only one oval.

- Yes
- No
- Maybe

Section 2 - The Subway Train Car

(STUDENTS WOULD ONLY COMPLETE THE FOLLOWING SECTION IF THEY ANSWERED "The Subway Train Car" FOR QUESTION 1 - They would not see the next section)

6. For each of the following statements, choose whether you agree or disagree.

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I liked the analogy activity as a story.					
I wish the analogy activity was more visual.					
I thought the story helped me visualize the concepts of active and passive transport.					
I would have enjoyed seeing a magic trick to explain this concept instead.					
A story is more engaging than a magic trick.					

Section 2 - The Card Trick

(STUDENTS WOULD ONLY COMPLETE THE FOLLOWING SECTION IF THEY ANSWERED "The Card Trick" FOR QUESTION 1 - They would not see the previous section)

7. For each of the following statements, choose whether you agree or disagree.

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I liked the analogy activity as a card trick.	⬭	⬭	⬭	⬭	⬭
I wish the analogy activity was less visual.	⬭	⬭	⬭	⬭	⬭
I thought the magic trick helped me visualize the concepts of active and passive transport.	⬭	⬭	⬭	⬭	⬭
I would have enjoyed hearing a story to explain this concept instead.	⬭	⬭	⬭	⬭	⬭
A magic trick is more engaging than a story.	⬭	⬭	⬭	⬭	⬭

NOTE: This survey would be given via Google Forms. This is just a printout to show the questions.

[i] As recommended by Wiseman and Watt (2020), the design of this magic intervention was created in collaboration with knowledgeable magicians, including the first author himself, who along with being a science teacher is a multi-award-winning magician who is regularly featured at the Chicago Magic Lounge.