Can Mindfulness Practice Improve Short-term Retention in a Science Course?

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Abstract
Brief periods of wakeful resting have a positive effect on memory consolidation. To test the impact of mindful breathing exercises on the retention of new knowledge in a science class, we assigned lab sessions of Anatomy and Physiology I and II randomly to the intervention group or control group. During teaching periods, the intervention group lab sessions integrated mindfulness breaks by having students participate in guided breathing exercises every 25-30 minutes. With one exception, the average scores on the weekly retention quizzes taken at the end of the lab sessions were higher for the intervention group compared with the control group for all quizzes in both Anatomy and Physiology I and II. However, there was no significant difference in the average score between the intervention and control groups on formal quizzes and exams. Future studies should evaluate whether mindfulness techniques, such as mindful breathing exercises, used before exams lead to improved exam scores. https://doi.org/10.21692/haps.2021.001

Key words: wakeful resting, memory formation, mindfulness, mindful breathing exercises, Anatomy & Physiology

Introduction
In 1900, one of the founding fathers of experimental psychology, Georg Müller and his student Alfons Pilzecker, published their seminal work *Experimental Contributions to the Science of Memory* (Experimentelle Beiträge zur Lehre vom Gedächtnis)(Lechner et al. 1999). They proposed that memory formation is not an instantaneous process, but requires time to consolidate. Therefore, interruptions may negatively affect memory formation. Although this concept of memory consolidation was soon accepted, its importance and implications for teaching and learning were not fully recognized. Most research in this area focused on the benefits of sleep and its influence on forming memories. It was not until early in the twenty-first century, when studies were published that looked at factors affecting memory formation in patients with amnesia. For example, Dewar et al. (2009) reported that some of the severe forgetting observed in amnesia is actually the product of a disruption of memory consolidation by immediate post-learning interference.

Wakeful resting, which is a brief period of minimal mental stimulation after new learning, allows for novel memory traces to be consolidated better and therefore retained for much longer (Dewar et al. 2012). Craig et al. (2016) showed that wakeful rest can improve the integration of new spatial memories. A recently published review article by van Kesteren and Meeter (2020) stressed that offline periods, in which learners are allowed to let their mind wander, have a positive effect on memory consolidation. Analogously, Martini et al. (2020) found that, similar to sleeping after learning, a brief period of wakeful resting after encoding new information supports memory retention.

One way to achieve wakeful resting is by drawing the mind away from a mental or physical task to focus on ourselves, thus becoming mindfully aware of our body and emotions. Mindfulness can be defined as nonjudgmentally paying attention to the present moment (Kabat-Zinn 1994). The two main components of mindfulness are: present-moment awareness and acceptance (Ahmed et al. 2017). While mindfulness practices are often considered in conjunction with Eastern spiritual practices, they are gaining popularity in the classroom for young children through adolescents and college students (Franco et al. 2011; Joy et al. 2019; Leland 2015).

The positive effects of mindfulness on overall well-being, including the emotional and mental health of students, have been well documented (Szpunar et al. 2013; Warnecke et al. 2011). However, most studies involving undergraduate students focus on the beneficial effects of mindfulness on mental health and sleep, as opposed to learning and academic performance (Rosenzweig et al. 2003; Shapiro et al. 1998; Sohrabi et al. 2013).

For example, Gray et al. (2018) found significant decreases in stress levels and heightened sleep quality for undergraduate students who participated in a brief mindfulness-based intervention. Firth-Clark et al. (2019) explored the use of cognitive behavioral techniques to improve academic performance of student-athletes. Both researchers concluded that mindfulness on its own is not the most effective intervention, and thus should be used as an adjunct to other psychological methods.

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To evaluate the effect of mindfulness on the performance of college students, this study addressed the following two questions:

1) Does integration of mindfulness practices into formal teaching increase retention of newly learned material?
2) If there is a positive effect on knowledge retention, does this lead to better performance on formal assessments and better grades?

Additionally, we were curious about student reactions to the integration of mindfulness practices into the classroom and whether they would see benefits beyond improved knowledge retention.

Methods

Ethical research statement

The research protocol and its amendment were approved by the Institutional Review Board of Florida Gulf Coast University (FGCU) prior to data collection (FGCU IRB 2018-57). All researchers involved in the study were trained in ethical data collection through the Collaborative Institutional Training Initiative (CITI). Data collection followed all laws relevant to the survey of university student populations.

Data collection

During academic year 2018/19, lab sections in both Human Anatomy with lab I (Anatomy and Physiology I) and II (Anatomy and Physiology II) were randomly assigned to either the intervention group or the control group. Both groups used the same course materials, followed the same syllabus, and used the same written tests to assess student progress. The only difference was that, during teaching periods, the intervention group lab sessions integrated mindfulness breaks by having students participate in guided breathing exercises every 25-30 minutes. The lab sessions lasted two and a half hours with an initial teaching period of 45 minutes to one hour, which meant there were usually two breaks for guided mindfulness. During the guided breathing meditation, the students sat up straight, closed their eyes, and listened to a five-minute recorded breathing exercise. Students were encouraged, but not required, to actively engage in the guided breathing exercise.

Students in both groups completed short quizzes of ten multiple choice questions at the end of each weekly lab session to assess their retention of the material covered during the session. Additionally, students in both Anatomy and Physiology I and II took nine weekly quizzes and four written exams during the term. The number of questions on these quizzes and exams ranged from 15 to 125 depending on how many chapters in the textbook were covered.

Students in the intervention group were invited to participate in three anonymous online surveys to assess their perceptions of the mindfulness breaks at the start of the semester, midway through the semester, and at the end of the semester.

Data analysis

Statistical analyses were performed using the SPSS, version 26.0, statistical software package from IBM. All data were analyzed using a confidence interval of 95% and a significance level of 0.05. The data were analyzed for normal distribution using the Shapiro-Wilk test of normality. All data were normally distributed with $P>0.05$ so that the assumption for parametric statistics was satisfied. To identify if a significant difference between groups existed, the paired sample *t* test was used to compare the difference between both groups each week. Where a significant difference between intervention group and control group was identified, the Cohen's d effect size was determined.

Results

Study population

The number of students in our Anatomy and Physiology classes dropped over the course of both semesters and not all students attended all lab sessions or took all weekly quizzes and exams. In Fall 2018, 214 students started the semester in seven lab sections; four lab sections were assigned to the intervention group and three lab sections to the control group. There were 349 students in 12 Anatomy and Physiology I lab sections in Spring 2019; half of the lab sections were assigned to either the intervention or control group. Anatomy and Physiology II had 225 students in eight sections in Fall 2018 and 177 students in six sections in Spring 2019. At the beginning of each semester, the lab sections were randomly assigned to either the intervention or control group.

Weekly retention quizzes

The thirteen weekly quizzes administered at the end of each lab session consisted of ten multiple choice questions. The questions were designed to assess how much of the material covered during the lab sessions students actually remembered. The quizzes did not factor into the students' overall course grades.

In Anatomy and Physiology I, the average scores on all quizzes were higher for the intervention group compared to the control group (Table 1). However, the difference between the scores of the intervention and control group was only significant for quizzes 4, 5, 7, 8, and 10-13. There was no significant difference for the average scores between the two groups for quizzes 1, 2, 3, 6, and 9. The Cohen's d effect size for quizzes 4, 5, 7, 8, and 10-13 ranged between 0.257 and 0.500, indicating a small to moderate effect size as a result of the intervention.

For Anatomy and Physiology II, the average score on weekly retention quizzes was higher for the intervention group compared to the control group for all quizzes, except for quiz 4 when the control group had a higher average score (Table 1). There was no significant difference between the average scores

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of the intervention and control groups for quizzes 1, 2, 4, and 6-9. Significant differences in average scores between the two groups were, nonetheless, found for quizzes 3, 5, and 10-13. The Cohen's d effect size for these quizzes ranged from 0.258 to 0.407, i.e., showing a small to moderate effect size for the intervention.

	Anatomy & Physiology I				Anatomy & Physiology II			
	Intervention group	Control group	p-value	Effect size	Intervention group	Control group	p-value	Effect size
Quiz 1	7.5	7.3	0.198		8.3	8.0	0.072	
Quiz 2	7.5	7.4	0.542		7.6	7.5	0.615	
Quiz 3	7.3	7.3	0.683		7.0	6.5	0.017*	0.258
Quiz 4	6.3	5.7	0.007*	0.257	6.7	6.9	0.492	
Quiz 5	6.7	5.9	<0.001*	0.373	7.3	6.7	0.003*	0.323
Quiz 6	7.9	6.5	0.067		6.7	6.5	0.315	
Quiz 7	7.0	6.1	<0.001*	0.410	6.2	6.0	0.558	
Quiz 8	6.9	6.3	0.013*	0.247	6.1	5.8	0.308	
Quiz 9	6.1	5.9	0.329		6.7	6.6	0.701	
Quiz 10	8.8	5.9	<0.001*	0.376	5.4	4.9	0.029*	0.238
Quiz 11	7.3	6.1	<0.001*	0.500	7.2	6.4	<0.001*	0.407
Quiz 12	6.2	5.2	<0.001*	0.443	6.5	5.6	<0.001*	0.407
Quiz 13	6.6	5.3	0.013*	0.541	6.8	5.9	<0.001*	0.406

*denotes significance

Cohen's d effect size: small effect size = 0.2; moderate effect size = 0.5; large effect size = 0.8.

Table 1. *Average scores (out of 10) on weekly retention quizzes for the intervention and control group for Anatomy & Physiology I and II and p-values and Cohen's d effect size for significant p-values.*

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Quizzes and exams
Students in both Anatomy and Physiology I and II took nine weekly quizzes (multiple choice and open questions including labeling exercises) and four exams (multiple choice questions only). The quizzes covered one or two chapters in the textbook. Exams 1-3 covered between four and five chapters each. The last exam for both courses was cumulative and covered all chapters studied during the semester. As opposed to the weekly retention quizzes, the more formal quizzes and exams tested the students' knowledge from material covered the week(s) before. These assessments contributed 95% of the overall course grade at the end of the semester.

There was no significant difference in the average score between the intervention and control groups on any of the quizzes or exams. For example, the p-values for the four exams in Anatomy and Physiology II were 0.46 (exam 1), 0.10 (exam 2), 0.28 (exam 3), and 0.74 (exam 4), respectively. In general, the average scores for students in the intervention group were slightly higher, but there were also instances where students in the control group had higher averages.

Feedback surveys
The number of students completing the feedback surveys was rather low and declined from survey 1 to 3 (Table 2). At the beginning of the term, students in both Anatomy and Physiology I and Anatomy and Physiology II reported a generally positive attitude toward mindfulness practices. Six out of ten Anatomy and Physiology I (61.3%) and Anatomy and Physiology II students (62.5%) reported having practiced mindfulness, such as mindful breathing exercises or meditation, prior to taking this course. These students also reported a more positive attitude toward mindfulness practices than students who did not indicate prior exposure (7.4 vs. 5.6 for Anatomy and Physiology I; 7.3 vs. 5.0 for Anatomy and Physiology II).

	Survey 1 (week 1)		Survey 2 (week 7)		Survey 3 (week 15)	
	Anatomy and Physiology I	Anatomy and Physiology II	Anatomy and Physiology I	Anatomy and Physiology II	Anatomy and Physiology I	Anatomy and Physiology II
Number of respondents	n = 64	n = 56	n = 52	n = 48	n = 43	n = 42
Attitude toward mindfulness practices[1]	6.7	6.4	6.7	6.6	5.8	6.3
Has your attitude toward mindfulness changed during the semester?	n/a	n/a	Yes 32.7%	Yes 18.8%	Yes 19.0%	Yes 33.3%
Opinion of mindfulness breaks in labs[2]	n/a	n/a	6.7	6.0	6.5	6.2
Have mindfulness breaks been helpful? [3]	n/a	n/a	Yes 32.6%	Yes 36.5%	Yes 40.4%	Yes 35.7%
Student uses mindfulness breaks on their own[4]	n/a	n/a	Yes 26.9%	Yes 28.6%	Yes 20.8%	Yes 31.0%
Student plans on using mindfulness techniques in future[5]	n/a	n/a	n/a	n/a	Yes 39.5%	Yes 50.0%

[1]How would you describe your overall attitude toward mindfulness practices such as meditation? Scale 1 ('I just don't care for it') to 10 ('I love it')

[2]What do you think about the mindfulness breaks in labs? Scale 1 ('I hate them') to 10 ('I love them')

[3]Do you think the mindfulness breaks in labs have helped you remember things you learned in lab better? Yes/No

[4]Have you started to use mindfulness breaks/techniques on your own while studying for this or other classes? Yes/No

[5]Do you think you will continue to use mindfulness breaks/techniques on your own while studying after this course has ended? Yes/No

Table 2. *Results of feedback surveys 1-3 for Anatomy and Physiology I and II*

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The average score for the attitude toward mindfulness practices was basically unchanged at 6.7 for Anatomy and Physiology I and 6.6 for Anatomy and Physiology II on survey 2. One-third (32.7%) of Anatomy and Physiology I students felt their attitude toward mindfulness had changed during the term. These students had a score of 7.6 for their attitude toward mindfulness. Only 18.8% of participating Anatomy and Physiology II students reported a changed attitude toward mindfulness, however their average score for attitude toward mindfulness was fairly high at 8.4.

Anatomy and Physiology I and Anatomy and Physiology II students had similar scores (Anatomy and Physiology I 6.7; Anatomy and Physiology II 6.5) when asked to rate the mindfulness breaks used in lab on a scale from 1 to 10. Almost one-third (32.6%) of Anatomy and Physiology I students and 36.5% of Anatomy and Physiology II students felt that the mindfulness breaks had helped them remember content that they had learned in lab better. However, only 26.9% of Anatomy and Physiology I students and 28.6% of Anatomy and Physiology II students reported using mindfulness breaks/techniques on their own while studying for this or other classes at this stage of the semester.

On survey 3, Anatomy and Physiology I students reported a lower score for attitude toward mindfulness practices at 5.8 compared with 6.7 in surveys 1 and 2. The score for Anatomy and Physiology II students was more or less unchanged at 6.3. Only one-fifth (19.0%) of Anatomy and Physiology I students indicated a change in attitude toward mindfulness compared with one-third (33.3%) of Anatomy and Physiology II students who reported a change. The scores for '*What do you think about the mindfulness breaks in labs?*' were more or less unchanged for both student groups compared to survey 2.

The percentage of students who thought that the mindfulness breaks in labs had helped them remember things better was lower compared to survey 2 as well for both groups. On the other hand, more students had started to use mindfulness breaks/techniques on their own while studying for this or other classes since survey 2. The vast majority of these students indicated that they planned to use mindfulness breaks/techniques on their own while studying for future courses (Anatomy and Physiology I 92.3%; Anatomy and Physiology II 100%).

Discussion

The results of our study confirm the findings of previously published studies that integration of mindfulness breaks into the teaching/learning process improves short-term retention of studied material. With the exception of quiz 4 in Anatomy and Physiology II, the average scores on the weekly retention quizzes were higher for the intervention group compared with the control group for all quizzes in both Anatomy and Physiology I and II. Nonetheless, this is not an immediate effect but takes time and practice. The first quizzes with a significant difference in the average scores between intervention and control group were quiz 4 in Anatomy and Physiology I and quiz 3 in Anatomy and Physiology II. During the last part of the semester (week 10-13), the differences between the averages were statistically significant for all quizzes in Anatomy and Physiology I and II courses.

However, this increased retention of newly learned material did not carry over to quizzes and exams taken a week or more after the initial lab session in which the content was taught. For example, the average scores on the final exam of the term were only marginally different between the intervention group and the control group in Anatomy and Physiology I (62.2% for the intervention group vs. 59.8% for the control group) and almost identical in Anatomy and Physiology II (60.0% for the intervention group vs. 60.3% for the control group). This comes as no surprise as there many factors that influence student performance on formal exams. Students will have studied material repeatedly before taking an exam, thereby erasing any difference in immediate retention due to an integration of mindfulness practices.

Although almost one-third of students in the intervention group indicated in the feedback surveys that their attitude toward mindfulness practices had changed, the average rating on a scale from 1-10 did not reflect this change. The average score for the attitude toward mindfulness practices remained more or less unchanged over all three surveys. Students in both Anatomy and Physiology I and II who thought that the mindfulness breaks had helped them remember content better reported slightly better grades in survey 3. On the other hand, students who had started to practice mindfulness breaks/techniques on their own while studying for this or other classes did not earn better grades than those who did not.

Overall, four out of ten (39.5%) participating Anatomy and Physiology I students indicated that they planned on using mindfulness breaks/techniques on their own while studying for future courses; that percentage was even higher for Anatomy and Physiology II (50.0%). These participants had noticeably higher average scores for their attitude toward mindfulness (Anatomy and Physiology 7.2; Anatomy and Physiology II 7.7) than students who did not plan on using mindfulness techniques in future (Anatomy and Physiology 4.8; Anatomy and Physiology II 4.9).

Because the feedback surveys were anonymous and the number of responses very low, we were not able to analyze our data in more depth. Having more responses and being able to link them to student performance on quizzes and exams may have been able to yield more insight.

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Our next step will be to look at the impact of guided mindfulness on exam scores. Students regularly complain about being unable to perform well due to test anxiety. Having them engage in mindful breathing exercises before taking exams may help reduce their anxiety and improve their test performance.

Conclusions

Integrating mindfulness practices into teaching sessions/ lectures increases the immediate recall of the learned material, especially if the students are new to the subject matter taught. However, doing so does not lead to better scores on formal exams nor does it help students earn better overall course grades. There are other factors that affect the preparation for and/or performance in exams more. Future studies should evaluate if mindfulness techniques, such as mindful breathing exercises, used before exams lead to improved exam scores.

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Literature Cited

Ahmed K, Trager B, Rodwell M, Foinding L, Lopez C. 2017. A Review of Mindfulness Research Related to Alleviating Math and Science Anxiety. *J. Leadersh. Instr*. 16(2):26-30.

Craig M, Dewar MT, Harris M, Della Sala S, Wolbers T. 2016. Wakeful rest promotes the integration of spatial memories into accurate cognitive maps. *Hippocampus*. 26(2):185-193. https://doi.org/10.1002/hipo.22502

Dewar M, Alber J, Butler C, Cowan N, Della Sala S. 2012. Brief wakeful resting boosts new memories over the long term. *Psychol. Sci*. 23(9):955-960. https://doi.org/10.1177/0956797612441220

Dewar M, Garcia YF, Cowan N, Della Sala S. 2009. Delaying interference enhances memory consolidation in amnesic patients. *Neuropsychology*. 23(5):627-634. https://doi.org/10.1037/a0015568

Firth-Clark A, Sütterlin S, Lugo RG. 2019. Using Cognitive Behavioural Techniques to Improve Academic Achievement in Student-Athletes. *Educ. Sci*. 9(2): 89-104.

Franco C, Mañas I, Cangas AJ, Gallego J. 2011. Exploring the effects of a mindfulness program for students of secondary school. *Inter J. Know. Soc. Res*. 2(1):14-28.

Gray L, Font S, Unrau Y, Dawson A. 2018. The effectiveness of a brief mindfulness-based intervention for college freshmen who have aged out of foster care. *Innov.High.Educ*. 43(5):339-352. https://doi.org/10.1007/s10755-018-9433-3

Lechner HA, Squire LR, Byrne JH.1999. Learn Mem. Mar-Apr 6(2):77–87 http://learnmem.cshlp.org/content/6/2/77.full

Joy JM, Kohls MD, Shepherd LA. 2019. Mindful Minutes in the classroom. *IJONTE*.10(3):13-20.

Kabat-Zinn J.1994. *Wherever you go, there you are: Mindfulness meditation in everyday life*. New York: Hyperion

Leland M. 2015. Mindfulness and student success. *J Adult Ed*. 44(1):19-24.

Martini M, Marhenke R, Martin Ci, Rossi S, Sachse P. 2020. Individual differences in working memory capacity moderate effects of post-learning activity on memory consolidation over the long term. *Sci. Rep.* 10:17976 https://doi.org/10.1038/s41598-020-74760-z

Rosenzweig S, Reibel DK, Greeson J M, Brainard GC, Hojat M. 2003. Mindfulness-based stress reduction lowers psychological distress in medical students. *Teach Learn Med*.15(2):88-92. doi: 10.1207/S15328015TLM1502_03

Shapiro SL, Schwartz GE, Bonner G.1998. Effects of mindfulness-based stress reduction on medical and premedical students. *J Behav Med*. 21(6): 581-599.

Sohrabi R, Mohammadi A, Delavar A. 2013. Role and effectiveness of mind fullness education on students exam anxiety. *Procedia-Soc. and Behav. Sci. 84: 1639-1641. https://doi.org/10.1016/j.sbspro.2013.07.006*

Szpunar KK, Moulton ST, Schacter DL. 2013. Mind wandering and education: from the classroom to online learning. *Front Psychol*. 4:495.

van Kesteren MTR, Meeter M. 2020. How to optimize knowledge construction in the brain. *npj Science of Learning*. 5(5) Open Access. https://doi.org/10.1038/s41539-020-0064-y

Warnecke E, Quinn S, Ogden K, Towle N, Nelson MR (2011) A randomised controlled trial of the effects of mindfulness practice on medical student stress levels. *Med Educ*. 45(4):381-8

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The Power of Analogy-Based Learning in Science

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Abstract
Analogies are useful pedagogical tools to introduce new and difficult concepts to students by building connections to familiar things from our daily life. Research has shown that applying analogies during the learning process facilitates the development of higher order thinking. In this article, we present a number of analogies that have been included in several science courses, including anatomy and physiology and clinical chemistry, in undergraduate nursing science education. We also evaluated student perspectives on the ability of these analogies to enhance student understanding of difficult concepts. A total of 53 analogies were organized into structural and functional categories and a survey explored student feedback on them. A total of 131 first-year and second-year students completed the survey. More than 70% of the students indicated that these analogies were useful in understanding the anatomical structures and physiological functions. Over 60% of students applied these analogies while studying. Eighty-eight percent of students found that analogies were engaging and made the lecture more enjoyable. We conclude that well-structured and purposeful analogies have positive impact on students' learning of science courses during undergraduate nursing studies. https://doi.org/10.21692/haps.2021.003

Key words: analogies, metaphors, pedagogical, undergraduate science education, anatomy and physiology, educational research

Introduction
Analogy has been defined as a comparison based on some form of similarity between an unfamiliar and a familiar domain. Traditionally this relationship is expressed with "*a* is to *b* is like *c* is to *d*" (Richland and Simms 2015; Seiler and Huggins 2018). Other definitions emphasize the role of analogies in learning and the cognitive process in the transfer of information from a source (familiar) to a target (unfamiliar) domain to achieve a better understanding (Brown and Salter 2010; Dagher 1995; Gentner 1983; Gentner 1989; Gentner and Markman 1997; Orgill 2006). Hofstadter (2001) defines analogies as the perception of commonalities between the target and source domains and sees analogies as the link between the familiar and the unfamiliar. The author adds that our brain is continuously building analogies during the learning process to facilitate comprehension. To understand a new concept, whether it is scientific in nature or for everyday life, the human brain finds a familiar concept and links that to the unfamiliar (Hofstadter 2001). Metaphors are similar to analogies in referring to the similarity between two things, however metaphors implicitly state the comparison, such as the heart is a pump and vessels are the pipes (Brown and Salter 2010; Niebert et al. 2011). Furthermore, analogies are more complex in their nature than metaphors. When used as pedagogical tools, analogies often need an explanation to make sure student construction of the similarities is what the teacher intended (Dagher 1995; Brown and Salter 2010).

Gentner's structure mapping theory has been foundational in understanding analogies as scientific concepts. Brown and Salter (2010) explain that based on Gentner's theory, an analogy is well-developed and aids learning if the two domains share relations rather than attributes.

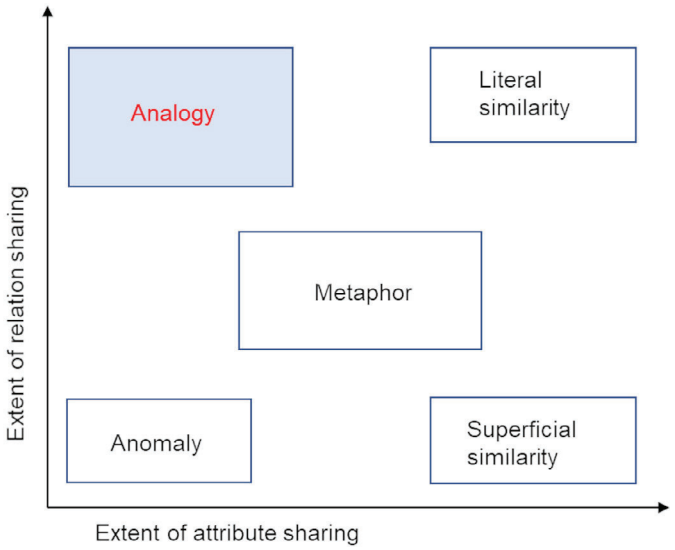

Figure 1. *The extent of relation and attribute sharing between the two domains. Analogies have greater extent of relation sharing. [Adapted from: Gentner (1989) and Brown and Salter (2010)*

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