Analogies, Content Knowledge, and Implications on Learning

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Abstract

Analogies appear to be ubiquitous as learning tools, and research suggests that they are useful in enhancing conceptual understanding when utilized properly. Yet, analogies are difficult to generate and are often mistaken for other modes of comparison. Even educators who possess sufficient content knowledge on a given topic can often struggle to implement quality analogies into their lessons. It is possible then, that content knowledge is not sufficient means to create or identify a quality analogy. Additionally, how does the quality of an analogy given before a lesson affect learning? This paper explores three studies that investigate these problems. Study 1 examines the relationship between content knowledge and analogy generation, where 76 participants were randomly assigned to one of four conditions in this 2 (Artifact, Biology) x 2 (Mechanism, History/Control) between-subjects design. There were 3 main parts to participants' experience: the lesson, the content knowledge questions, and analogy generation. Neither domain or content knowledge had a significant effect on the quality of the analogy generated. Study 2 was concerned with analogy quality identification, where 96 participants were placed into the same conditions as Study 1. Participants were given a "good" or "bad" analogy to rate on a 0-10 scale, instead of generating an analogy on their own. Content knowledge did not significantly affect participants' ability to identify a quality analogy, as there was no significant difference between conditions. Study 3 explored how, and if, the quality of an analogy, given before a lesson and quiz, impacted learning gains. Study 3 was a 2 (Domain: Artifact, Biology) x3(Analogy Quality: Good, Bad, No Analogy) between-subjects design, where 90 participants read a "good" or "bad" quality analogy, and subsequently read a lesson and took a quiz to measure learning. Study 3 showed that the quality of the analogy given did not significantly affect participants' learning.

Contents

1. Introduction

Analogies have long been utilized by educators to better explain novel concepts by relating what is new and unfamiliar to a topic or target that is familiar to the learner. Great teachers can even map a novel concept to a relatively unfamiliar analog, expanding students' knowledge on both targets simultaneously. The educational potential of analogies is perhaps the reason they are such a prevalent method of explanation. The ubiquitous nature of analogies though is the very foundation of their enigmatic state. Laypeople often mistake these devices for metaphors, literal similarities, abstractions, or other general comparisons (Gentner, 1983). As Dr. Gentner thoroughly unfolds in the structure mapping theory of analogies, there are specific distinguishing factors that apply strictly to analogies. Analogies differ from other methods of comparison in that analogies are not concerned with similar features between the "base" familiar concept, and "target" novel concept. Rather, the relational aspects between the base and the target are based on "syntactic properties of the knowledge representations," (Gentner, 1983). That is, analogies draw out parallels between structures of two topics. In her demonstration of analogy structure, Dr. Gentner presents an integral theme: analogies are unique. They obey underlying rules that do not rely on the superficialities of a domain; an important factor that helps distinguish them from alternate forms of association.

There is no denying that analogies are everywhere (Hoffman, 1983); they've even been called "the lifeblood of human thinking," (Brown & Salter, 2010; Hofstader, 2001). We so often employ comparisons and draw parallels that to communicate without doing so would seem ineffective, if not impossible. George Lakoff and Mark Johnson ("Metaphors We Live By", 2008) argue that metaphor is the basis of all thought, and that cognition is reliant upon linking partial understandings of concepts. Lakoff and Johnson's hard stance may be extreme, but their argument makes the important point of highlighting that concepts can often be "understood in terms of other concepts" (Metaphors, 2008). Putting aside the argument of what then spurs an individual's first, original thought, the idea that novel conceptual understanding is reliant on linking to familiar concepts, gives both metaphors and analogies enormous potential. Analogies are a celebrated lifeblood in educational discourse because the way in which these comparisons are systematically fashioned makes them a comprehensive instrument capable of "solving problems, constructing explanations, and building arguments" (Gentner & Holyoak, 1997).

Despite this ubiquity, an obstacle that must be overcome is the colloquial definition of analogies, which often become interchanged with metaphors. Dr. Gentner acknowledges their similarity; both require relational comparison and neither rely on attributes. Lack of a clear definition of either term in conversational discourse has muddled the two concepts. However, with careful analysis, one can see that they are different. Some metaphors do follow the structure mapping schema and exist as analogical tools, but for metaphors, "the mapping rules tend to be less regular than those for analogy," (Gentner, 1983) suggesting that analogical comparisons require a different level of organization and configuration. While metaphors are integral and significant, they don't provide the kind of rich structure mapping, unique to analogies. In this paper we will be investigating why analogies, despite their similarities to metaphors that are so automatic and integral to our ability to conceptualize information, are much more difficult to generate and integrate into our understanding of the world.

There is plenty of literature endorsing the use of analogies in the classroom. One study experimentally manipulated the use of an analogy in teaching students about light refraction. Upon evaluations three months later, results showed that the analogical approach aided in long term "conceptual change" (Treagust et al., 1996). Additionally, scientific literature has demonstrated that analogical methods of teaching are effective not just in academic materials and scientific content, but also in motor learning. A 2017 study by Tse, Fong, Wong, and Masters, regarding motor learning attempted to utilize analogies, quoting previous psychological research demonstrating that instruction via analogy can "enhance acquisition and understanding of knowledge." Tse et al.'s 2017 study investigated the usefulness of analogies in teaching students a novel motor skill, namely, skipping rope." They discovered that when taught using an analogy, children performed significantly better than kids who were in the control group taught by "explicit protocol" (Tse et al., 2017). This study suggests that analogies are not only useful in the classroom concerning topics of academia, but have the possibility to aid in the realization of physical concepts, with "potential benefits related to reduced cognitive processing requirements," (Tse et al., 2017).

Research such as Tse et al. (2017), and Treagust et al. (1996) provides evidence that analogies are useful both in the classroom and beyond, yet it is still essential to discuss the implications of their potential limitations. This can help to clarify the ways analogies can be utilized in the most efficient way to advance concept acquisition. Another study by Gick and Holyoak (1980) was conducted to test people's proficiency with analogies. The researchers tested how well a subject would map base knowledge onto the target problem. Subjects were given one of two stories before being asked to try to solve a problem. The control group was presented with a random story, but the story presented to the experimental group importantly contained key causal elements that were analogical to a problem later presented to both groups. While the two stories did not bare resemblance in surface feature, they had "major analogical relations between them" (Gick & Holyoak, 1980).

The group given the analogous story successfully generated an analogous solution to the problem (Gick & Holyoak, 1980). Despite the potential benefits of having read an initial story whose structure mirrored that of the later target problem, researchers recognized that a limitation to successfully utilizing analogies could be due to “failure to spontaneously notice its pertinence to the target problem.” In other words, when participants were not explicitly instructed to draw connections and inspiration from the previously presented story, significantly fewer subjects generated an analogous solution (Gick & Holyoak, 1980). Gick and Holyoak’s research suggests that, although analogies have the depth and capability to be useful scaffolds for developing deeper understanding, people may have trouble with analogy generalization without explicit direction.

Despite this, the given notion is that analogies are ubiquitous (Hoffman 1983) and therefore easy and useful for learning purposes. Not only are they found universally, but it is even understood that very young children before receiving an education “develop a capacity for analogical thinking” (Holyoak &Thagard, 1997). Nonetheless, this elementary “capacity” may not be enough to truly benefit from advanced analogies presented by educators. If both parties were well-equipped with the intricacies of the structural complexity of analogies, it could enable students to gain the full effects of these useful learning mechanisms. Despite the supposed benefits, “their wide use in teaching is often problematic because of the applicability of specific analogies is not negotiated to students” (Aubusson et al., 2006).

Some strategies were offered in Brown and Salter’s 2010 analysis titled “Analogies in Science and Science Teaching.” These researchers suggested that students should not only be taught analogies, but *about* analogies. They also note that educators should “take care to develop good analogies.” This would be beneficial, as educators possess extensive content knowledge on a topic they attempt to teach using an analogy. However not all teachers are well-versed on the structure mapping components of analogies (Gentner, 1983). This lack of background knowledge about a learning tool itself can impede educators from offering the most useful analogy for a concept. Furthermore, these researchers suggest for teachers to “explicitly explain the structure of the analogy and its limitations,” however, again this cannot be done without the educator first understanding the background of analogical theory. Another advantageous suggestion is to use more than one analogy (Gick & Holyoak, 1983; Holyoak & Koh, 1987) as this can help bridge the relational connectivity between the base and the target. The way analogies are taught now do not account for the complex way in which analogies “convey a system of connected knowledge” and that they are not just “a mere assortment of independent facts.” These complexities are not understood at the level necessary for students to completely appreciate and the comparison and then apply it to novel situations (Gentner, 1983).

In our current studies, we examine the relationship between sufficient content knowledge and analogies. Because analogies have the potential to be advantageous tools if used properly, we examined if having adequate content knowledge is necessary and sufficient to generate quality analogies. This has implications in learning environments, as all teachers likely have sufficient content knowledge, however we explore if that alone is adequate enough to generate useful analogies for students. Additionally, we investigate if content knowledge is useful in basic identification of high quality versus low-quality analogies; can people with content knowledge identify what makes an analogy a valuable one? Furthermore, we examine how reading a high quality versus low quality analogy before reading a lesson impacts learning potential. Recognizing how content knowledge and analogies are related is an essential step when attempting to offer solutions to analogy use across educational platforms.

2. Study 1

The first study explores the rather troubling nature of generating analogies. In this study, we examine how well adults can generate analogies for a given stimulus randomly assigned to them. Subjects read a lesson containing either "biological stimuli" where they read about antibiotics, or "artifact stimuli," a lesson about toilets. Subjects were also randomly assigned to one of two conditions, either receiving a lesson containing mechanistic content knowledge about the stimuli or a history lesson about the stimuli, with no content knowledge. After participants read their assigned lesson, they were presented with 20 True or False questions: 10 that relate to the mechanism of the stimulus, and 10 that probe their historical understanding. The test was given in order to measure learning between those given a content knowledge lesson versus those given a control history lesson. After subjects completed the quiz, they were asked to generate an analogy about their assigned stimuli. The analogies were graded using a predetermined rubric (see Appendix for more detailed description of survey materials). When grading the analogies, the experimenters were blind to the condition of the participants.

We predict that the analogy scores from the two conditions, content knowledge versus no content knowledge, will have no significant difference. We also anticipate that despite the stimulus given, artifact or biology, the graded analogy scores will show no significant difference. We predict there will be no effect from domain (artifact or biology) or content knowledge on the analogy generation scores. We believe that generating good analogies is a unique skill that is not contingent upon sufficient content knowledge nor dependent upon the type of stimulus.

2.1 Methods

2.1.1 Participants

A multiple regression power analysis based on pilot results revealed N = 73 adults would be sufficient to detect a medium effect size at .8 power. This number was rounded up to N=76 participants to ensure an equal number of participants per condition. N= 16 participants were excluded for either failing attention checks, comprehension checks, or not providing analogies. Participants were adults from Amazon Mechanical Turk.

2.1.2 Procedure

Conditions: Participants are randomly assigned to one of four conditions in this 2 (Artifact, Biology) x 2 (Mechanism, History/Control) between-subjects design: Artifact Mechanism, Artifact Control, Biology Mechanism, or Biology Control. There were 3 main parts to participants' experience: the lesson, the content knowledge questions, and analogy generation.

Introduction: Participants are told what an analogy is and that they will need to generate an analogy of their own that is appropriate for teaching 12-year-olds about the content.

Manipulation/Lesson: Participants are then shown the lesson corresponding to their condition. Each lesson contains comprehension check questions within the lesson to promote engagement. Each lesson contains images or gifs and text is broken up so as not to be overwhelming.

Dependent Measure A: After the lesson, each participant responds to all content knowledge questions. Content knowledge DVs are T/F format and contain 20 total questions about both history and mechanism to control for participant confidence. Mechanism DVs correspond to the core causal concepts used to develop the rubric used to rate the quality of analogies.

Dependent Measure B: Participants are then asked to generate an analogy that can explain the content of the lesson to a 12-year-old. Analogy quality is rated by two coders, blind to condition, using a rubric created based on pilot studies. The rubric rates analogies based on whether specified key causal concepts (Artifact = 5, Biology = 4) are sufficiently explained (2), just mentioned (1), or absent (0). The analogy scores of the mechanistic content knowledge group were compared to the analogy scores of the history control group. Additionally, the analogy scores across domains were compared.

2.1.3 Materials

Participants were presented with one of four lessons, depending on their condition (for lessons, see appendix). Participants were then asked to respond to 20 True or False questions that probed for understanding of the content. (for content knowledge questions, see appendix)

The materials in Study 1 include:

One survey. This survey included:

An introduction to analogies.

A question with a scale for participants to rate perceived difficulty of analogy generation and quality of analogies by teachers (pre and post lesson)

A lesson relating to the stimulus, either with mechanistic content knowledge, or irrelevant historical information, which served as the control condition. Each lesson had interspersed comprehension questions to ensure participants were paying full attention to the given lesson.

An assessment with 20 True or False questions, this included 10 questions relevant to their lesson (mechanistic or historical) and 10 questions pertaining to the other lesson they did not receive (mechanistic or historical). This quiz was given to ensure that the participants learned something from the lesson which would demonstrate content knowledge.

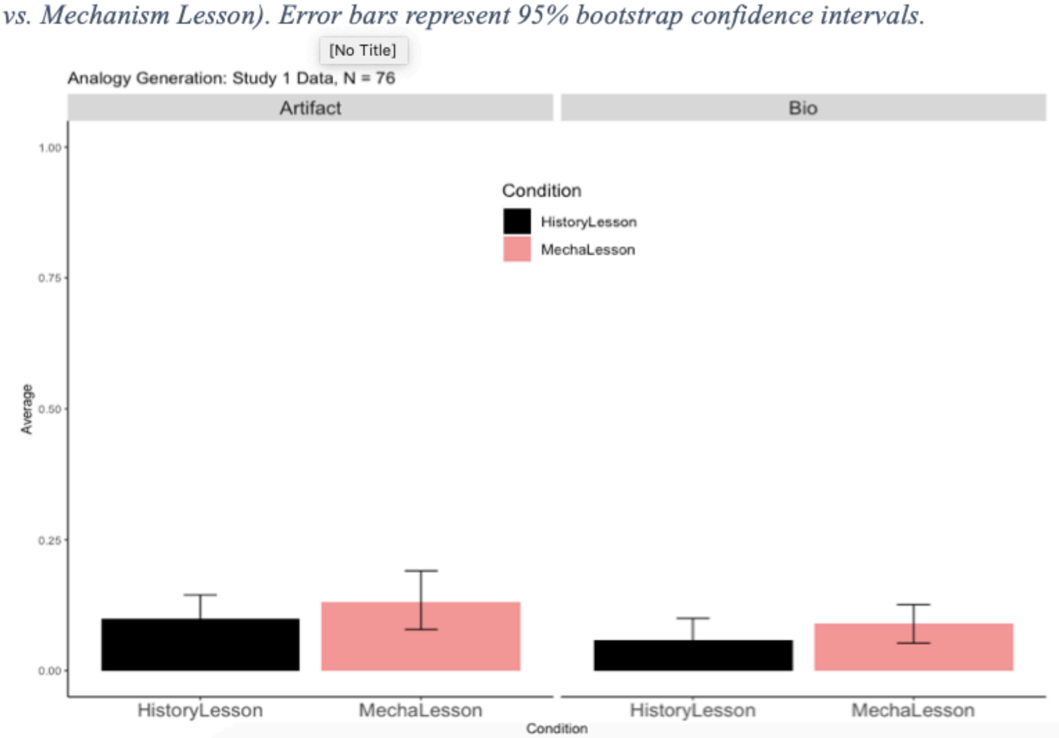
A prompt asking participants to generate an analogy to explain to a 12-year-old how the participants' respective given stimuli works.

A rubric created by experimenters based off of causal components of each stimulus used to score the analogies generated by the participants. The rubric rates analogies based on whether specified key causal concepts (Artifact = 5, Biology = 4) are sufficiently explained (2), just mentioned (1), or absent (0).

2.2 Results

A generalized linear model revealed no significant effect of either Content Knowledge condition ($p = 0.25$) nor Domain ($p = 0.35$) on participants' ability to generate a quality analogy. Figure 1 compares the average generated analogy score for each condition, and shows no significant difference between the scores from the participants in the History condition compared to the Mechanistic condition. Additionally, Figure 1 shows that there is no significant difference in scores across the domain, Biology (antibiotics) versus Artifact (toilet).

Figure 1: Results from Study 1. Participants were asked to generate analogies about either an artifact stimulus (toilet) or biological stimulus (antibiotics), respective of domain condition. There was no significant effect of domain nor of content knowledge condition (History Control vs. Mechanism Lesson). Error bars represent 95% bootstrap confidence intervals.



2.3 Discussion

From this study, we found that content knowledge is not sufficient means to create a good analogy. While people intuitively think of analogies as easy to generate and readily identifiable, they cannot generate quality analogies of their own even with the benefit of having sufficient content knowledge. People's inability to spontaneously generate analogies provides a new perspective for the role of analogies in classroom settings. While teachers have extensive content knowledge on a given topic, we have demonstrated that this knowledge, though likely necessary, is insufficient to promote the generation of quality analogies.

3. Study 2

As Study 1 provides evidence that content knowledge does not impact one's ability to generate quality analogies, Study 2 investigates whether and to what degree mechanistic content knowledge facilitates the ability to identify good analogies and differentiate them from bad analogies. All participants are randomly assigned to rate one analogy of their assigned stimuli. However, only half of participants previously receive a lesson with mechanistic content knowledge about the stimuli, while the other half receive a lesson about the history of that stimuli. We anticipate that the group who receive relevant content knowledge would rate the analogies more appropriately, corresponding to the experimenter ratings, than compared to the control group. From Study 1, we learn that content knowledge is not sufficient for quality analogy generation, however we still expect there to be a relationship between content knowledge and analogies of that stimuli. In Study 2 we investigate to what extent we find this relationship, more precisely, if it exists in the realm of quality analogy identification.

3.1 Methods

3.1.1 Participants

A multiple regression power analysis based on pilot results revealed that N= 95 participants would be sufficient to detect a medium effect size at .8 power. This number was rounded up to ensure an equal number of participants per condition. N = 96 participants (43 females, Average age = 37.6 years old) were run via Amazon Mechanical Turk. N = 6 participants were excluded and replaced for failing attention checks or multiple comprehension checks.

3.1.2 Procedure

The design was identical to Study 1, with the exception of the dependent measure. In Study 2, rather than generating their own analogy, participants were asked to rate analogies generated and pre-scored by experimenters using the same rubric in Study 1.

Conditions: As in Study 1, Study 2 is a 2(Artifact, Biology) x 2 (Mechanism, History (Control)) between-subjects design: Artifact Mechanism, Artifact Control, Biology Mechanism, or Biology Control. There were 3 main parts to participants' experience: the lesson, the content knowledge questions, and analogy rating.

Manipulation/Lesson: Participants were randomly assigned to read a lesson corresponding to their assigned condition. As in Study 1, each lesson is broken up into short segments and contain comprehension check questions, as well as appropriate images and gifs pertaining to their stimuli.

Dependent Measure A: Participants completed the same 20 question True or False quiz from Study 1 to record content knowledge acquisition. This assessment contained 20 total questions about both history and mechanism to control for participant confidence. Again, mechanism DVs correspond to the core causal concepts used to develop the rubric used to rate the quality of analogies.

Dependent Measure B: Then, subjects were told what an analogy is, and that they will need to rate an analogy on a scale from 0-10 in its effectiveness to teach 12-year-olds about the content. Participants were randomly assigned one analogy about their assigned stimuli. These analogies were designed by experimenters and graded on the same rubric used in Study 1 before being randomly distributed for participant rating.

3.1.3 Materials

Participants were presented with one of four lessons, depending on their condition (for lessons, see appendix). Participants were then asked to respond to 20 True or False questions that probed for understanding of the content (for content knowledge questions, see appendix).

The materials in Study 2 include:

One survey with biological stimulus. This survey included:

A lesson relating to the stimulus, either with mechanistic content knowledge, or the control historical condition. These lessons had interspersed comprehension questions to ensure participants were paying full attention to the given lesson;

An assessment with 20 True or False questions, this included 10 questions relevant to their lesson (mechanistic or historical) and 10 questions pertaining to the other lesson they did not receive (mechanistic or historical). This was given to ensure that the participants learned something from the lesson which would demonstrate content knowledge;

An introduction to analogies;

A prompt with analogy they were randomly assigned. This prompt asked participants to rate the given analogy on a scale from 0-10 in its perceived effectiveness in “teaching 12-year-olds” about the respective stimuli.

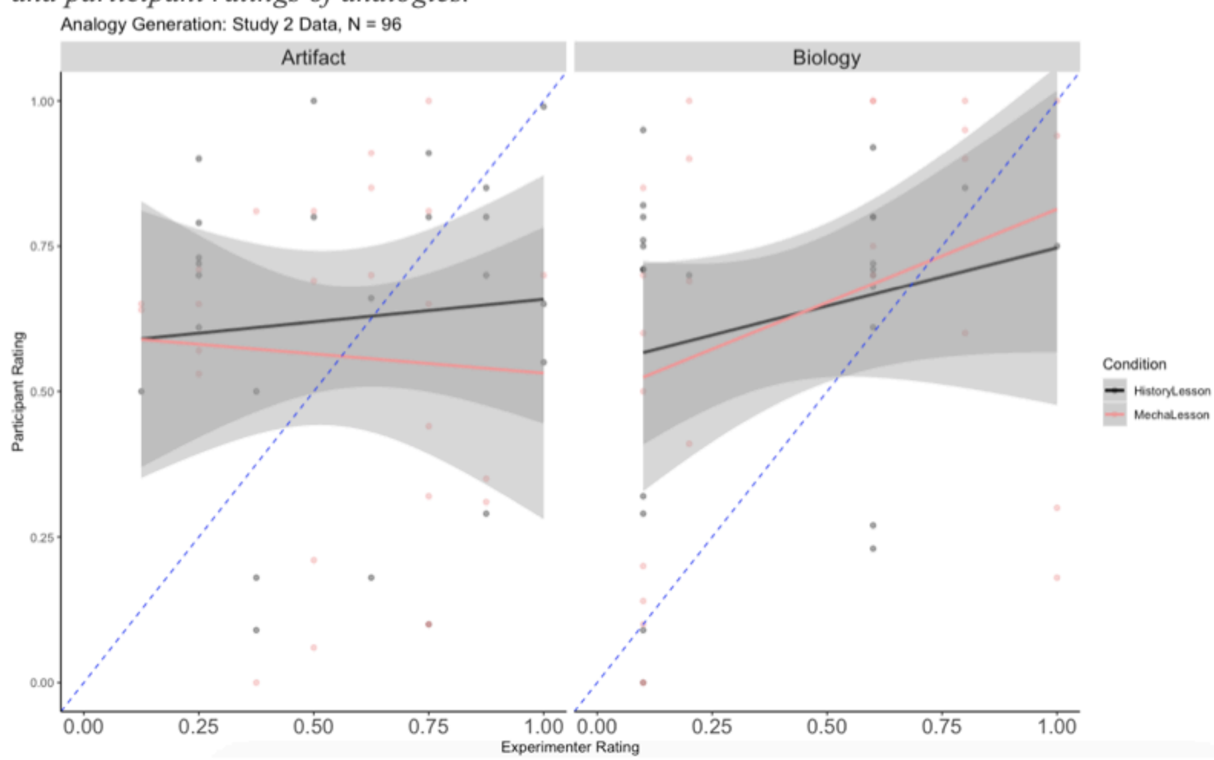
3.2 Results

A linear regression revealed no significant effect of either Domain ($p = 0.84$), Content Knowledge ($p = 0.93$), or Analogy Quality according to Experimenter Ratings ($p = 0.71$). If there were a strong correlation between participant ratings of analogies and objective experimenter ratings of analogies, Figure 2 would include a 45-degree line in each graph (a blue dotted line is included for reference).

3.3 Discussion

The data shows that contrary to what we anticipated, content knowledge has no significant effect on how well participants' analogy rating scores predict experimenter scores.

Figure 2: Results from Study 2. Participants in the X condition and Y condition showed no significant difference in their ability to identify good vs. bad analogies. The X-axis indicates the quality of analogies used as stimuli according to the key causal elements rubrics used in Study 1. The blue line indicates a perfect correlation between Experimenter Rating (rubric scores) and participant ratings of analogies.



While we hypothesized that content knowledge would improve participants' ability to accurately score analogies, the data from Study 2 suggests otherwise. This could be due to the lack of knowledge participants have concerning what constitutes a quality analogy. It suggests that there is more to quality analogy identification than simply knowing about the topic. Perhaps this data suggests that a deeper understanding of analogies is warranted for accurate analogy identification.

4. Study 3

In Study 3, we examine how an analogy paired with a mechanistic content knowledge lesson impacts subjects' learning. More precisely, we are interested in the relationship between the quality of the learned analogies and participants' scores on a related True or False quiz. In Study 3, subjects are randomly assigned to one of the same two stimuli seen in Studies 1 and 2. Then, subjects are given one mechanistic analogy of that stimuli to scaffold their understanding, before reading the mechanistic content knowledge lesson. Subjects are subsequently quizzed on the mechanistic information with a 10-question mechanistic true or false test.

Since the analogy quality is variable among the 10 analogies in each stimulus, we expect that an analogy's quality level will predict the scores that participants receive on the content knowledge quiz. We expect that participants who receive higher quality analogies paired with a content knowledge lesson will present higher scores on the content knowledge quiz. We predict that subjects who receive a low-quality analogy will not benefit from their given analogy. Furthermore, we expect that their learning might even be hindered when compared to the learning in the control group who received no analogy before their mechanistic lesson.

4.1 Methods

4.1.1 Participants

A multiple regression power analysis revealed that N=85 participants would be sufficient to detect a medium effect size at .8 power. This number was rounded up to ensure an equal number of participants per condition. N = 90 participants (28 females, Average age = 38.4 years old) were run via Amazon Mechanical Turk. N = 15 participants were excluded and replaced for failing attention checks or multiple comprehension checks.

4.1.2 Procedure

Conditions: Study 3 is a 2 (Domain: Artifact, Biology) x3(Analogy Quality: Good, Bad, No Analogy) between-subjects design. Participants were randomly assigned to one of six conditions: Good Artifact Analogy, Bad Artifact Analogy, Artifact No Analogy, Good Biology Analogy, Bad Biology Analogy, No Biology Analogy.

Manipulation: Subjects will receive one analogy, scored by experimenters using the same rubric from Studies 1 and 2. These analogies range on a scale from 0 to 10, 10 being a quality analogy according to the rubric. Then, subjects read the mechanistic lesson from their assigned condition which included attention checks and comprehension questions to ensure participants were engaged with the material.

Dependent Measure: Participants completed a 10-question mechanistic true or false quiz, where the 10 questions were the same mechanistic questions used in the surveys from Studies 1 and 2. These correspond to the core causal concepts used to develop the rubric the experimenters used to create and score the analogies. Experimenters scored the quizzes and investigated the relationship between the quiz results and the scores of the analogies that the participants received.

4.1.3 Materials

Survey includes:

One of 20 analogies generated by the experimenters.

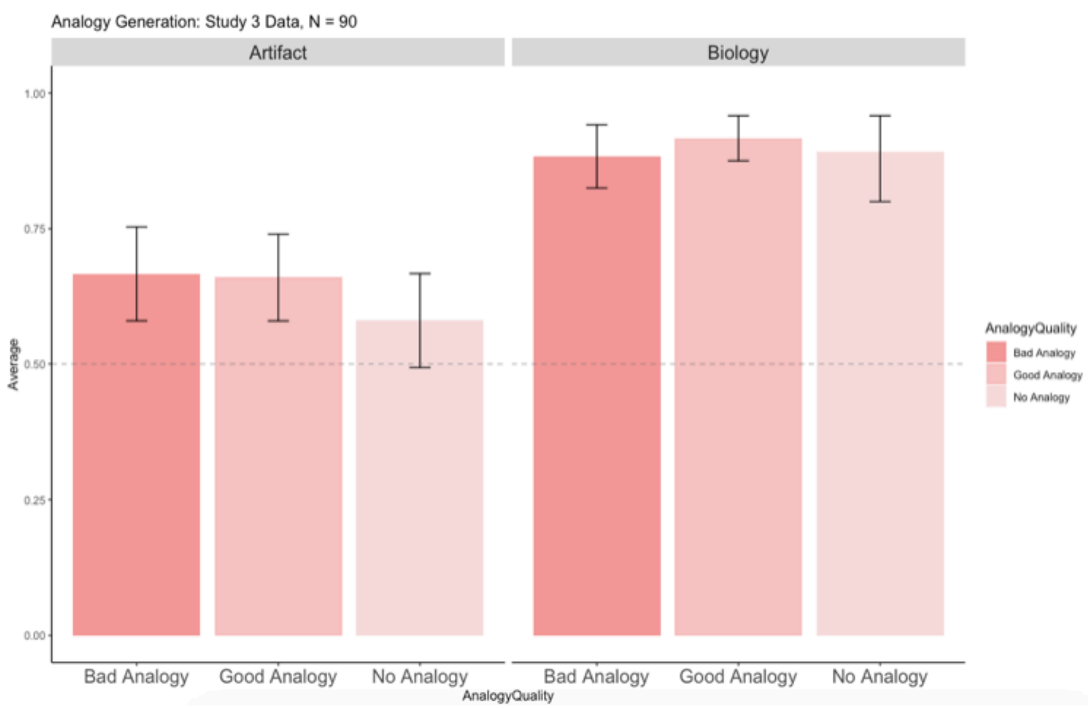
Mechanistic lesson pertaining to their condition including interspersed attention checks and comprehension questions to ensure full engagement.

10 mechanistic True or False questions about the given lesson.

4.2 Results

A linear regression revealed a significant effect of Domain ($\beta = 0.217$, $p = 0.84$) in that participant's content knowledge scores in the Biology condition were significantly better than

Figure 3: Results from Study 3. Participants read either a high-quality analogy, a low-quality analogy, or no analogy before completing a lesson and a quiz to measure learning. There was no significant effect of analogy quality on participants' learning. Additionally, participants in the Artifact condition scored lower on the content knowledge test than those in the Biology condition. Error bars represent 95% confidence intervals.



those of participants in the Artifact condition. Counter to our hypotheses, there was no significant effect of Analogy Quality ($p > 0.05$).

4.3 Discussion

Study 3 provides evidence that, despite our initial hypothesis, the quality of the analogy participants received before reading the mechanistic lesson and taking the content knowledge assessment did not affect their score on the assessment. This could be due to the lack of time between learning the analogy and lesson, and taking the quiz. Without sufficient time between learning and testing, crucial extrapolation of the analogy and lesson material may not have happened as naturally or efficiently as it would in a classroom setting.

Additionally, domain had an effect on the content knowledge assessment, as participants in the Biology condition scored higher. This was also counter to our hypothesis. One reason that this occurred could be due to the possibility that the biology lesson about antibiotics was easier or more intuitive for participants, and therefore they were able to score higher on the assessment.

5. General Discussion

From our studies we can conclude that quality analogies are difficult to generate, and that domain and content knowledge have minimal effect on the quality of a generated analogy, despite people’s intuitions. A difficulty in analogy generation despite adequate content knowledge emphasizes that content knowledge is not sufficient for analogy generation, suggesting that there is more to creating a useful analogy than just subject comprehension. Previous literature on analogies describes how current cultivation of analogies involves sufficient content knowledge, but usually does not involve the dynamic of how analogies work structurally.

Further research is necessary to investigate whether having a basic understanding of the structural components of analogies combined with content knowledge is sufficient to create analogies that positively impact learning in educational environments.

We also can conclude that domain and content knowledge have no significant effect on how well participants accurately rated the quality of an analogy. These results did not align with our initial hypothesis. We anticipated that having content knowledge about a stimulus would aid participants' ability to identify a good analogy for that stimulus, however we did not find this effect. This could be due to the fact that the average score of the analogies that participants were asked to rate in Study 2 was significantly higher than the average scores of the analogies participants generated (Study 1 data).

It is possible that because of this discrepancy, participants viewed most experimenter-generated analogies as "good," even in cases where they read a lower quality analogy, because their interpretation of a "good" analogy was skewed. It could be helpful in a future study to implement a condition where participants learn the causal components of the stimuli in addition to receiving content knowledge, because a more precise idea of a "good" analogy could be helpful before being asked to rate. Initially, we hypothesized that analogies are easy to identify, however this may only be true with the combination of content knowledge and possibly insight on analogical structure, which can be explored with further studies.

Furthermore, our results from Study 3, which attempted to investigate the impact of analogy quality on learning, showed no significant difference between conditions of reading a high-quality analogy, low quality analogy, and no analogy (control) before reading a mechanistic lesson. Since both high- and low-quality analogy conditions showed the same learning results, one could say this outcome could be due to, as mentioned above, the disparity between the experimenters' idea of a quality analogy and the reality of the participants' average analogy score.

However, this is not a plausible explanation because the control condition, who received no analogy before the lesson, showed the same learning scores as participants who read analogies. More realistically, these results could be due to the lack of delay between learning and test taking. In classrooms, there is significant time between students learning a topic and being tested, which allows them to extract important information, such as causal components, from material they learn. It is possible that because of the nature of the survey, without time in between learning the analogy and taking a quiz, participants were unable to fully take advantage of the analogy as best as they could.

The results from these three studies reiterate that analogies are a challenging aspect of teaching and learning alike, despite initial preconceptions about their universal nature. Potentially, our studies emphasize that not only are analogies a difficult concept, but that maybe in addition to content knowledge, they could be most successful when the analogical components are outlined and their limitations defined to the learning party *and* to those attempting to generate an analogy (Brown & Salter, 2010). Furthermore, it would suggest that experts and amateurs alike both struggle with the generation of analogies, which would lead to implications and future work to narrow the many questions which have evolved throughout this study. Therefore, as suggested in Brown & Salter (2010), perhaps educators as well as students would benefit from learning the necessary structural components of a quality analogy, which can be explored in future studies.

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6. Appendix

6.1 Materials

6.1.1 Artifact Mechanism Lesson:

- A toilet has two main areas: the bowl and the tank, as noted in the diagram. When you want to flush a toilet, you would press the handle down.
- Pushing down on the handle on the outside of the toilet pulls up on a part called the "flush valve chain" inside the tank. So, when the handle is pushed down, the flush valve chain is pulled up, opening up the flush valve.
- Opening the flush valve allows water from the tank to fill the bowl, where the water will carry waste to the sewer. As the water flows into the bowl, it flows out of the tank, lowering the water level within the tank.
- Please complete the following statements.
    - The handle triggers the flush valve chain to pull on the:
    - Opening this, lets water flow from the tank to the:
- A part inside of the tank, called a "float ball," floats on top of the water within the tank. So, as the water exits the tank to fill the bowl, the water level in the tank drops and so the float ball lowers.
- The float ball is attached to a valve, called the "inlet valve." When the float ball lowers it opens the inlet valve, allowing water from the supply pipe to refill the tank.
- As water flows into the tank, the water level rises and so does the float ball, eventually closing the inlet valve once more. When the inlet valve closes the new water supply is stopped.
- Please complete the following statements.

  - o When the water level drops, the float ball:
  - o When the _________ is opened, the water from the supply pipe refills the tank.

- Once flushed, the toilet cannot be flushed again until this float ball returns to its initial position. For example, if a toilet is re-flushed too soon, then the tank will not have been filled with enough water. If there is only minimal water that flows through the flush valve and into the bowl, then there will not be enough pressure to wash away the dirty water to the sewer. This is why you might experience that after flushing, although you push down on the handle, the toilet does not flush again.
- Please complete the following statements.
- A toilet cannot properly do its job unless the system has returned to its ________.
- If a toilet is re-flushed too soon, then there will not be enough ________ to wash away the dirty water into the sewer.
- The toilet's ability to be flushed again is dependent on whether it has completed the jobs and functions prompted by the previous flush. Therefore, if any of the parts in a toilet failed to do its job then the toilet would be unable to properly function. For example, if the handle was not connected to the flush valve chain, water would never flow from the tank to the bowl. If any part in the chain of events fails to properly do its job, then the toilet will not flush. Evidently, all of the parts of the toilet and how they work together are necessary for the toilet to function properly.
- Please complete the following statements.
  - o Water would not be able to flow from the tank to the bowl is the flush valve chain detached from the:

- All parts of the toilet and how they work together are ______ for the toilet to function properly.

6.2 Materials:

6.2.1 Artifact Control (History) Lesson

- The modern toilet has evolved from many earlier, more basic models of sanitary waste disposal. Initial toilets were incredibly basic compared to the convenient systems that modern plumbing allows.
- In ancient Rome, toilets were located in public bathhouses, lined up next to one another. People used this public space and treated it as a social gathering. This model of "porta-potty" type toilet remained unchanged until the "commode" replaced them in wealthy households
- Commodes consisted of a seat, a cover, and a pot. A commode's pot was similar to the bowl of a modern toilet. However, the pot was simply a container that lacked any plumbing where the waste would be carried off to sewage.
- Please fill in the blanks:
    - ______ pot was similar to the bowl of a modern toilet.
    - People would treat the toilet as a ____ place.
- In 1592, Sir John Harrington invented the first flush toilet. However, his invention was not popularized for centuries. Although Sir John Harrington is credited as the inventor of the flush toilet, Alexander Cumming was granted a patent for the flush toilet in 1775.
- In the 1850s, it became increasingly common to have a washroom inside of personal residences. At this time inventor Thomas Crapper was called on to build and improve toilets in royal chambers
- The flush toilet was not only a revolutionary invention because of the convenience it provided to everyone. It was also an extremely significant factor in the decline in water borne illness rates, like cholera.
- Please fill in the blanks:
    - ____ was called on to build toilets in royal chambers.
    - The flush toilet was invented by ___ in 1592.
- More modernly, there are tanks on top of a bowl, with flushable valves to eliminate the waste. These contemporary methods use considerably less water than was necessary for the early flush toilets in the 16th century. However, even in the 20th century, most toilets used around 6 gallons per flush. It wasn't until the 1980s when the amount decreased to 3.5 gallons per flush. Yet, this amount was still considered wasteful. Thus, in 1994, a law was introduced to limit toilets to 1.6 gallons per flush, which is a significant decrease.
- Please fill in the blanks:
- Now, there are tanks on top of a ____.
- These new methods use considerably ___water than in the 16th century.
- Now, there are automatic flush toilets which many public restrooms take advantage of. These toilets utilize a sensor apparatus to detect motion, and send a signal to flush the toilet. Automatic toilets can increase sanitation since there is no mechanical touching of the handle, which can often be covered in bacteria. This is especially useful in public restrooms due to the spread of various infectious microbes and germs. However, they can be quite wasteful because these toilets can trigger a flush even when one is not necessary. Or, they can fail to trigger a flush even if the user is presenting motion to the sensor.
- Please fill in the blanks:
- These toilets utilize a _______ apparatus to detect motion.

- They can be quite ______ because these toilets can trigger a flush even when one is not necessary.

6.3 Materials:

6.3.1 Artifact Content Knowledge Questions

- A1F - True or False: First, the handle is pushed down. Next, the inlet valve is opened, allowing new water to flow into the tank, triggering the toilet to flush.
- A2F - True or False: Once the flush valve chain is pulled up, the flush valve opens, allowing new water to flow into the tank and triggering the toilet to flush.
- A3T - True or False: If the flush valve chain were to break, then water would not be able to flow through the flush valve and into the bowl.
- A4T - True or False: If the flush valve was broken and could not close, the float ball would never float high enough to close the inlet valve.
- B1F - True or False: You must wait to flush a toilet a second time because a toilet cannot flush until the mechanisms are back in place and the tank is empty of water.
- B2F - True or False: Once a toilet is flushed, you need to wait until the flush valve opens before pushing down on the handle to flush again.
- C1T - True or False: When a toilet is flushed, water rushes from the tank into the bowl through the flush valve, but more water must eventually flow into the tank from the inlet valve to restore initial water levels.
- C2F - True or False: Because the float ball is connected to the flush valve and floats at different heights depending on the water level, it controls when water is able to flow through the flush valve.
- C3F - True or False: Water in the tank needs to return to its standard level after the flush. To maintain this initial water level the inlet valve opens, allowing water to flow from the tank into the bowl.
- C4T - True or False: Once the toilet is flushed, the float ball drops down with water levels, pulling the inlet valve open and allowing new water to flow into the tank from the supply line.
- H1F - True or False: In Roman Times, toilets were located in private spaces, and in some cases, inside the homes.
- H2F - True or False: The commode had a seat, a cover, and a flush mechanism.
- H3F - True or False: The commode contained a pot, which usually was made of wood.
- H4F - True or False: In the 19th century, the inventor Thomas Edison built toilets in royal chambers.
- H5T - True or False: John Herrington was the first inventor of the flush toilet in 1592, but did not receive the patent for it.
- H6T - The most important contribution of the flush mechanism in toilets is the reduction of water-borne illnesses.
- H7F - True or False: To reduce water-borne illnesses, modern toilets use more water in a flush than did toilets in the past decades.
- H8F - True or False: In 2006, there was a law passed to regulate the amount of water used in a single flush.
- H9T - True or False: Automatic toilets are useful in increasing sanitation in restrooms while also decreasing infection rates.
- H10F - True or False: Automatic toilets are more efficient than manual flush toilets because using a motion sensor allows less water to be wasted.

6.4 Materials:

6.4.1 Artifact Analogy Rubric

- *Target Causal Concepts:*
  - *A*
    - *Chain of events (4 main trigger parts are connected)*
    - *A causes B causes C*
  - *B*
    - *Broken chain (counterfactual)*
  - *C*
    - *Refractory period (can't be flushed until full of water again, takes time)*
  - *D*
    - *Homeostasis (return to initial water level & close off inlet valve)*
    - *Float ball (must return to original position)*
  - *E*
    - *Water level / closing of inlet valve*

	CAUSAL CHAIN *(DOMINO EFFECT)*	**BROKEN CHAIN** *(NECESSITY OF EACH PART)*	**REFRACTORY PERIOD**	**HOMEOSTASIS**
0	*No mention*	*No mention*	*No mention*	*No mention*
1	*Mention chain*	*Mention broken chain*	*Mention refractory period*	*Mention homeostasis*
2	*Elaborate upon chain*	*Elaborate upon broken chain*	*Elaborate upon refractory period*	*Elaborate upon homeostasis*

Score = Causal Chain + Broken Chain + Refractory Period + Homeostasis

6.5 Materials

6.5.1 Biology Experimenter Analogies: "Good" Analogies

1. Water gun – A toilet works like a water gun. Pulling the trigger on the water gun causes water to flow from the chamber through the barrel and out of the gun. Once the trigger is released water can flow from the reservoir to the chamber, refilling the chamber so that the water gun is ready to shoot again. This is just like how in a toilet, pushing the flush handle pulls open the flush valve, sending water from the tank to the bowl and how once the handle is released the flush valve closes, opening the inlet valve and allowing new, clean water to flow into the tank so that the toilet is ready to flush again. In both a water gun and a toilet one thing causes another to do its job, and if any part breaks then the whole system won't work and the water gun won't be able to shoot and the toilet won't be able to flush. Once the water gun is shot and once the toilet is flushed, each system needs time so that the water can get back to its initial levels in the tank (toilet) and in the chamber (water gun) before all of the parts are reset and ready to work again.

- 8/8
- Chain (2), Broken Chain (2), Homeostasis (2), Refractory Period (2)
- 208 Words

2. Basketball Team – A toilet works like a basketball team. First, to start the play in basketball, someone inbounds the ball, then the point guard carries the ball up the court toward the basket and finally the team tries to score. A toilet also has a specific series of parts that must all do their jobs at the right time, one after another. If any one player on a basketball team or part in the toilet doesn't do its job, then the team won't score and the toilet won't flush properly. Each player has a different but important job to do, just like each part of the toilet. A basketball team cannot continuously score once they make a basket – they have to wait for the other team to inbound the ball and for the play to reset before getting their chance again to score. Similarly, a toilet cannot continuously flush; there needs to be a break between flushes so that the system is able to reset. So just like a toilet needs a moment to return to its initial state before being flushed again, so too does a basketball team need a moment to reset before being able to score again.
   a. 7/8
   b. Chain of Events (2), Broken Chain (2), Refractory period (2), Homeostasis (1),
   c. 191 Words

3. Neuron– A toilet works like a neuron. Ions like calcium and potassium travel in and out of nerve cells, called neurons. When the neuron fires, sending a signal to muscle cells or other neurons, ions flow into the cell body, then the neuron quickly pushes the ions down to the end of the cell through a part called the axon, where the ions are forced back out from the end of the cell. This neuron firing is similar to how a toilet flushes: first the flush handle is pushed, which causes the valve to open, letting water flow from the tank to the bowl and out to the sewer. Just like a neuron cannot continuously fire, a toilet cannot continuously flush. A neuron needs time to bring in ions so that there is enough to force them back out upon firing. Similarly, a toilet needs time for water to flow from the inlet valve into the tank before it is ready to be flushed again. After firing, the neuron allows potassium and calcium cells to move in an out of the cell so that the neuron can return to its initial state before it is able to fire again. This is just like how, after being flushed, a toilet cannot do its job again until the water level in the tank returns to normal and the float ball floats up again, closing off the inlet valve.
   a. 6/8
   b. Chain (2), Homeostasis (2), Refractory Period (2)
   c. 235 Words

4. Ice Cream Machine – A toilet works like a soft serve ice cream machine. In an ice cream machine, the ice cream is stored in a freezer container. Once you pull the lever on the machine to dispense the ice cream, this causes the ice cream to travel down a series of tubes, eventually making its way to the nozzle. Once it gets to the nozzle, then it is "eliminated" from the machine onto the cone. This is similar to how a toilet functions. In a toilet, the water is resting in the tank. Once the flush handle is pulled, different pieces in the tank are triggered to move and open to allow water flow to the bowl. Then, the pressure from the flush causes the water and waste to flow into the sewer line. If any one

part of the ice cream machine were to break, it would break the chain of events and the ice cream would be unable to flow to the nozzle to be dispensed, similar to how if one of the many important pieces in a toilet were to break, the toilet would not be able to complete its flush. After a flush is completed, the user must wait to flush again until initial water levels are met because if there is no water in the tank, it would not be able to flush. It would be like trying to pull the handle of an ice cream machine without enough ice cream in the freezer container.
   a. 6/8
   b. Chain of events (2), broken chain (2), refractory period (1), homeostasis (1)
   c. 247 Words

5. Digestive System – A toilet works like your digestive system. Pushing the flush handle of the toilet causes clean water to flow from the tank to the bowl, and dirty water out to the sewage system. This is similar to how swallowing food forced new nutrients into your digestive system and eventually your digestive system excretes waste. If any part of your digestive system, such as your stomach, was unable to do its job, then you would not be able to digest any food at all because each part of the digestive system relies on the other parts to do their jobs as well and everything must be done in the correct order. Similarly, toilets have a specific process that allows them to flush and if any one part failed to do its job with proper timing, then the toilet would be unable to flush. The digestive system helps the body take in essential nutrients that it needs to keep its sodium, water, and nutrient levels at homeostasis. This is just like how a toilet has to return to homeostasis between each flush.
   a. 5/8
   b. Chain (2), Broken Chain (2), Homeostasis (1)
   c. 180 Words

6.5.2 Biology Experimenter Analogies: "Bad" Analogies

6. Post Office – A toilet works like a post office sending mail. To send a letter, you first put the letter in an envelope with the labelled address and a stamp. Then, you drop off the letter at the post office where workers read the address on the envelope and sort it amongst other letters, according to its destination. Finally, when the letter gets delivered to the most local post office, the local mail-carrier hand delivers the letter to the address. If there was no address on the letter, or if any step along the way had been messed up, then none of this process would have happened successfully and the letter would not have been delivered. This is similar to how a toilet flushes: there is a specific process that occurs and if any part of that process is broken, then the entire series of events would fail and the toilet would not be flushed. Each part is important both in sending a letter and in flushing a toilet. Each process also follows a specific order. With a toilet the water must flow from the tank through the flush valve and into the bowl. With a letter, the letter must travel from sender to destination.
   a. 3/8
   b. Chain of events (2), Broken chain (2)
   c. 202 Words

7. Subway Restaurant - A toilet works like a subway restaurant. When you want a sandwich from Subway, a worker will ask you what bread you want, which starts the sandwich making process. This is similar to how when you want to flush a toilet, you press down on the handle. Then, the worker will ask what kind of meat, cheese, toppings, and condiments you want on your sandwich, which are the next crucial steps to making the sandwich. This can be compared to the flush valve chain pulling up on the flush valve to let water rush out of the tank into the bowl. Both involve a chain of events that build on one another to get the job done! Without one step being completed, the function cannot be fulfilled. The sandwich maker makes one sandwich at a time, so if there is a line, the people have to wait patiently until the worker is finished making the other sandwich. Similarly, once you flush a toilet, you must wait until you can flush it again.
    a. 3/8
    b. Chain of events (2) refractory period (1)
    c. 185Words

8. Laundry Shoot – A toilet works like a laundry shoot. A laundry shoot is a built-in vertical tunnel inside a house that looks like a chimney, except it connects to the laundry room instead of a fire place. To use a laundry shoot you first open the hatch, then you throw your clothes into shoot, and finally the clothes fall down the shoot and into a hamper waiting at the bottom. So a laundry shoot helps you get rid of dirty laundry that needs to be washed. This is similar to how when you flush a toilet it triggers a particular set of events to occur, one after the other. Just like how the laundry shoot gets rid of your dirty laundry, a toilet gets rid of dirty waste water by sending clean water from the tank to the bowl and dirty water from the bowl to the sewage system. A laundry shoot involves a series of events and ends with a disposal of material, just like a toilet does. A laundry shoot is also like a toilet in many superficial ways – laundry shoots are made of metal and help transport things, just like toilets have metal piping to help transport water. Laundry shoots send laundry down to a laundry room or basement where the clothes will eventually be washed, cleaned, and used again. Toilets send dirty water to the sewage system, which often filters, cleans, and after enough processing, eventually returns the once dirty water as clean water meant to be used again.
    a. 2/8
    b. Chain of events (2) OR 1/8???
    c. 251 Words

9. Garbage Disposal – A toilet works like a garbage disposal. When you flip the switch on a garbage disposal, it starts a chain of events which grinds up the food and water into a manageable material to be disposed of. This is similar to when you press the flush handle on the toilet it starts a chain of events that causes water to be sent through a series of valves to the bowl to wash away the waste. Both involve getting rid of waste in a clean and sanitary matter by using water to send the waste down the drain and to a designated location.
    a. 2/8
    b. Chain of events (2)
    102 Words

10. Vacuum - A toilet works like a vacuum. Toilets are designed to carry away waste. Vacuums are also designed to transfer and eliminate waste. When you press the "On" button of the vacuum, the suction turns on and pulls waste and dust into the nozzle. Then, the waste moves up the vacuum into the main chamber. This chamber collects all the dust and dirt that is suctioned up until it can all be thrown away. The way dust flows through a vacuum is similar to how water flows through a toilet. First, water comes in and fills the tank, then that water is flushed down into the bowl and eventually out to the sewage system. When the dust bag or chamber of a vacuum fills with waste and dust, it must be emptied and thrown out. Similarly, a toilet when flushed carries away waste and dirty water to be disposed of. Vacuums and toilets are essential to maintaining a clean and sanitary home and each of them can be found in nearly every home in America.
    a. 1/8
    b. Chain of events (1)
    c. 168 Words

6.6 Materials:

6.6.1 Biology Mechanism Lesson

11. People can take antibiotics when they have a bacterial infection, like strep throat, but not when they have a virus, like the Flu.
12. Antibiotics are able to target the bacteria in your body, and impede them from building cell walls, copying their DNA, and building protein.
13. There are different types of antibiotics that target bacteria in these different ways; Beta-Lactam stops bacterial cells from building cell walls, Macrolides stop bacterial cells from copying their DNA, and Quinolones prevent bacterial cells from building proteins.
14. Please complete the following statements.
    a. People can take antibiotics when they have a _____ infection, like strep throat.
    b. Antibiotics impede bacteria from copying their _____.
    c. The types of antibiotics that target bacteria are namely Beta-Lactam, ______, and Quinolones.
15. Although antibiotics are efficient at targeting just bacteria, they fail to differentiate which bacteria to attack.
16. Although bacteria is often associated with the kinds of germs that get you sick, some bacteria are good. Your body is composed of many good bacteria, like probiotics, which help your body maintain a strong internal system and are essential for your health.
17. When taking antibiotics, the medication is unable to differentiate between good and bad bacteria. So, taking antibiotics kills not only the bacteria making you sick, but also those that keep you healthy.
18. While taking antibiotics to treat an infection can be beneficial, taking antibiotics for a long period of time can eliminate the good bacteria that keep you healthy, leading to negative health consequence.
19. Please complete the following statements.
    a. Antibiotics ___ to differentiate which bacteria to attack.
    b. When you take antibiotics, it also kills the _____ bacteria that you need.
    c. Taking antibiotics for a ____ period of time can have negative health consequences.

6.7 Materials:

6.7.1 Biology Control (History) Lesson

20. In 1909 a German physician names Paul Ehrlich discovered a treatment for Syphilis that is widely considered to be the first contemporary antibiotic.
21. In 1928 one of the most famous antibiotics was discovered by Alexander Fleming. This discovery of Penicillin was proven to treat staph infections.
22. Penicillin was discovered just prior to onset of World War II and ended up playing a crucial role in the outcome of the war; many injured soldiers were saved from painful deaths because of this new antibiotic.
23. Please fill in the blanks:
    a. The chemical known as the first contemporary antibiotic was a treatment for _____.
    b. In 1928 _____ was discovered by Alexander Fleming.
    c. This drug helped stop the growth of _____.
24. Penicillin is used as a treatment for a variety of diseases, including Pneumonia and Scarlet Fever.
25. Although Penicillin is often associated with the positive effects of eliminating the effects of disease, there can be negative effects for a limited number of people. While it is rare, some people have adverse reactions to the treatment, developing rashes, fever, or anaphylaxis.
26. Penicillin quickly became a widely available treatment. In the following decades, many new antibiotics were discovered. However, the discovery of new antibiotics eventually slowed and few have been discovered since the mid-20th-century.
27. Years after the discovery of Penicillin, another antibiotic, known as Cephalexin, was discovered. This antibiotic can be used to treat a variety of cases, such as Urinary Tract Infections or skin infections.
28. Please fill in the blanks:
    a. People can use ______ for reasons such as Pneumonia or Scarlet Fever
    b. Some people have ____ reactions to Penicillin which can manifest in a variety of ways
    c. Some common uses of Cephalexin include treatment for _______ and skin infections.

6.8 Materials:

6.8.1 Biology Content Knowledge Questions

29. A1F - True or False: To prevent infections from spreading, antibiotics selectively target bacteria, meaning that the antibiotics differentiate and attack bad bacteria, but not good bacteria.
30. A2T - True or False: To prevent infections from spreading, antibiotics non-selectively target bacteria, meaning that the antibiotics do not differentiate good bacteria from bad bacteria.
31. B1T - True or False: Because antibiotics can differentiate between body cells and bacterial cells, they are a safe short-term treatment for bacterial infections.
32. C1T - True or False: The Flu is a viral infection, so antibiotics would not be an effective treatment.
33. D1T - True or False: Antibiotics prevent bacteria from copying their DNA, which leads to there being fewer bacterial cells in the body.
34. D2T - True or False: Antibiotics prevent bacteria from producing proteins, which leads to them being unable to survive and reproduce.
35. D3F - True or False: Antibiotics help white blood cells to copy their DNA more quickly, which helps create more white blood cells to fight the infection.
36. E1F - True or False: Over long-term antibiotic use, the good bacteria builds up, which can result in digestive issues or fungal infections.
37. H1F - True or False: In the 18th Century, Paul Ehrlich discovered a treatment for Syphilis, which was known as the first antibiotic.
38. H2F - True or False: In the 20th century Alexander Fleming discovered Penicillin, a drug that he found to help with Staphylococcus.
39. H3F - True or False: Because Penicillin was mass-produced, it contributed significantly to the health of soldiers and civilians during World War I.
40. H4F - True or False: The majority of antibiotics were discovered toward the end of the 20th Century, due to more advanced scientific methods.
41. H5F - True or False: Cephalexin is a harsher antibiotic which must not be used for infections of the skin.
42. H6T - True or False: Penicillin allergic reactions can cause patients to develop symptoms such as fever, rash, and in rare cases, anaphylaxis.
43. H7F - True or False: Cephalexin is an antibiotic that was discovered before Penicillin.
44. H8F - True or False: The chemical that was known as the first contemporary antibiotic was called arsphenamine

6.9 Materials:

6.9.1 Biology Analogy Rubric

45. Target Causal Concepts*:*

a. A
   i. Non-selective targeting (good bacteria vs. bad bacteria)
b. B
   i. Selective targeting (bacteria vs. bodily cells)
c. C
   i. Limited effectiveness (bacteria vs. virus)
d. D
   i. Multiple processes/methods of implementation (DNA vs. Cell wall vs. Protein synthesis)
e. E
   i. *Unintended Consequences (side effects)*

	NON-SELECTIVE TARGETING *(GOOD VS. BAD BACTERIA)*	**SELECTIVE TARGETING** *(BACTERIA VS. BODY CELLS)*	**LIMITED EFFECTIVENESS** *(BACTERIA VS. VIRUSES)*	**MULTIPLE PROCESSES** *(DNA VS. CELL WALL VS. PROTEIN SYNTHESIS)*	**UNINTENDED CONSEQUENCES** *(SIDE EFFECTS, LONG TERM USE)*
0	*No mention*	*No mention*	*No mention*	*No mention*	*No mention*
1	*Mention non-selective targeting*	*Mention selective targeting*	*Mention limited effectiveness*	*Mention multiple processes*	*Mention unintended consequences*
2	*Elaborate upon non-selective targeting*	*Elaborate upon selective targeting*	*Elaborate upon limited effectiveness*	*Elaborate upon multiple processes*	*Elaborate upon unintended consequences*

7.0 ***Materials:***

7.0.1 Biology Experimenter Analogies: "Good" Analogies

1. Weapon - Antibiotics work similar to a special weapon that is designed to kill a certain type of dangerous creatures who live in Community X (bacteria) while protecting Community Y (body cells). It is impossible for the gun to know which creatures in Community X are good or bad so it kills any Community X creature, like how antibiotics they kill both good and bad bacteria. The weapon can protect in multiple different ways, by neutralizing Community X's building supplies, and by attacking their forts, just like how antibiotics attack bacteria cell walls and bacteria's protein. The weapon only works against creatures of Community X (bacteria), and wouldn't work against other types of dangerous creatures such as Community Z (viruses). There are negative side effects of

the weapon; if it is not used carefully or for too long, then it can not only harm Community X, but it can also put Community Y in danger! Similarly, if antibiotics are used for too long, harm can be done to the body.

f. 10/10
g. Non-selective (2), Selective (2), Limited Effectiveness (2), Multiple Processes (2), Unintended Consequences (2)
h. 168 Words

2. Firehose - Antibiotics work like a firehose. The firehose extinguishes the fire and prevents it from causing damage to the rest of the neighborhood, just like antibiotics eradicate bad bacteria to prevent damage to the body. The person using a firehose is trying to put out the fire as quickly as possible, before the burning destroys the whole house and eventually the rest of the neighborhood. The firehose cannot douse the fire without getting the house wet, leading to potentially serious water damage to the building. Similarly, antibiotics kill off bad bacteria, but also kill some good bacteria as well. Leaving a firehose running forever might extinguish the fire, but it would also destroy the house and flood the neighborhood, just as taking antibiotics for too long might have negative side effects. Further, a firehose is useful against fires, but cannot protect a house from a tornado, just like how antibiotics can fight off bad bacteria, but not viruses.
    a. 8/10
    b. Non-selective (2), Selective (2), Limited Effectiveness (2), Unintended Consequences (2)
    c. 157 Words

3. Pesticides - Antibiotics work like pesticides. Pesticides kill off pests from a garden in the same way that antibiotics kill off unwanted bacteria in the body. Pesticides kill bugs that are harmful, leaving the good plants healthy and able to grow. Antibiotics kill off bacteria, but do not hurt our body cells, protecting us from harm. However, just like some bugs in a garden are good because they help with pollination, some of the bacteria in the body are good for our health. But pesticides, like antibiotics, cannot tell the difference between bugs (bacteria) that are helpful from those that cause harm and make us sick. Antibiotics or pesticides can be helpful to fix short term problems like a bug infestation or a bacterial infection, using either of these things for too long can have negative consequences. For example, using too many pesticides could leave too few bugs to help pollinate the garden. Using antibiotics for too long can leave too few good bacteria, causing nausea, vomiting, or diarrhea.
    a. 6/10
    b. Non-selective (2), Selective (2), Unintended Consequences (2)
    c. 167 Words

4. Bleach - Antibiotics work much like bleach does. Bleach can help keep white clothes clean and bright, but can also ruined colored clothing. Antibiotics (bleach) treats all bacteria (clothes) the same, killing off harmful bacteria along with good bacteria in the gut. This is like how bleach will remove dirt and stains (bad bacteria) from clothing, but will also strip out the dye (good bacteria) that gives clothing its color. However, just like

how bleach affects clothing without ruining the washing machine, antibiotics can have powerful effects on bacteria without doing damage to body cells. While bleach (antibiotics) cannot differentiate within types of clothing (bacteria), its effects are limited so they don't affect the washing machine (body cells). While antibiotics and bleach can do good, using too much or using them too many times can have negative consequences. For example, using bleach too often can quickly thin and wear out clothing. Similarly, using antibiotics for too long can kill off too many good bacteria and lead to nausea, vomiting, or diarrhea.

   a. 6/10
   b. Non-selective (2), Selective (2), Unintended Consequences (2)
   c. 170 Words

5. Vacuum - Vacuums are useful tools to pick up dirt on your carpet. They work by using suction. This means if you have a lost earring on the carpet, and you unknowingly run the vacuum over it, it will suck up your earring along with other dirt. The vacuum does not selectively pick which particles it sucks up. This is similar to how antibiotics work. Antibiotics' job is to kill bad bacteria (carpet dirt), however it also kills good bacteria (the earring) too because it cannot differentiate between, just like the vacuum does not differentiate between carpet and dirt, but has limited/no effect on the carpet itself. So the carpet remains intact and unharmed, just like bodily cells remain unaffected by antibiotics. You cannot use vacuums in all clean up situations, for example, it would not be the correct tool to use if you had spilled juice on the carpet. This is just like how antibiotics are effective fighters against bacteria but not against viruses.
   a. 6/10
   b. Non-selective (2), Selective (2), Limited Effectiveness (2)
   c. 163 Words

7.0.2 Biology Experimenter Analogies: "Bad" Analogies

6. Dessert - Antibiotics can help fight off an infection in the same way that having some dessert can help to satisfy a sweet tooth. While eating dessert once in a while can be good and rewarding and help to satisfy a craving, if you eat too much dessert or eat dessert for too many nights in a row, then there can be negative health consequences. For example, eating an appropriate amount of dessert can be good, especially for your happiness! However, there are long term effects of over-indulging on dessert. For example, eating too much dessert can lead to obesity, Type II diabetes, cavities, or eventual heart disease. Antibiotics too can be good in appropriate doses: they help to cure sicknesses. However, if you take too many antibiotics or continue to use antibiotics for a prolonged period of time, then there can be negative health consequences as well, such as nausea, vomiting, indigestion, diarrhea, bloating, loss of appetite, etc.
   a. 2/10
   b. Unintended Consequences (2)
   c. 158 Words

7. New House - Taking antibiotics to fight an infection can be compared to buying a new, bigger house in a nice, gated neighborhood. People move houses for many reasons, such

as job location, size, and neighborhood safety, which might make them more inclined to move into a gated neighborhood. When you move into a bigger house with more safety benefits, you are gaining more space as well as luxury and security, which can make you feel more comfortable. However, leaving your old house also means leaving your memories and comforts from that space, which can be difficult. This is similar to how antibiotics work, because antibiotics are programmed to kill bacteria, but there are tradeoffs. Antibiotics do both good and bad things because while they are effective at killing the bad bacteria, they kill the good bacteria as well. Just like how buying a new house has tradeoffs, both good and bad, so does taking antibiotics since the good bacteria is eradicated with the bad bacteria.

   a. 1/10
   b. Non-selective (1)
   c. 163 Words

8. Police Dog- Antibiotics are like police dogs. Dogs trained to work with police officers can have any number of jobs that they are specifically trained to do. Some police dogs are trained to sniff for bombs or other dangerous devices, while other dogs are trained to track down people. Many dogs are trained so that when they find either drugs, bombs, or a missing person they immediately sit down. However, these dogs are sometimes distracted by the smell of food or treats, and so they also sit down in hopes of getting a treat as a reward. If a police dog sits, it may signal to a police officer that there is a serious threat, even though the dog is signaling for a completely different reason, namely, treats. Police dogs are similar to antibiotics because they fight against harm, but also because of the nature of how they operate; There are potentially dangerous unintended consequences from using police dogs or side effects from antibiotics.
   a. 1/10
   b. Unintended Consequences (1)
   c. 162 Words

9. Social Media - Antibiotics are similar to social media, because there are pros and cons to using both. Social media can be a great tool to stay connected with one’s friends from all around the world. However, social media also can cause people to compare themselves to others, sometimes resulting in feelings of negative self-image. Some studies even suggest that social media is a general distracter, promoting mind-wandering, which has been linked to unhappiness. Deleting social media accounts can help erase the negative aspects of social media out of one’s life, which can help increase one’s overall well-being. However, deleting social media accounts also comes with a cost, which is missing out on what all of your friends are doing, which might make you feel out of the loop. This is similar to how antibiotics work because antibiotics are programmed to get rid of the bad bacteria but they also get rid of the good bacteria too.
   a. 1/10
   b. Non-selective (1)
   c. 154 Words

10. White Board - Antibiotics work like erasing a white board. If there is both blue permanent marker and red dry erase marker on a white board, then using a dry eraser

would remove the red dry erase marker from the board, without getting rid of the blue permanent marker. This eraser is like antibiotics because antibiotics target and kill off the bad bacteria (red marker) that make people sick. Just like how the dry eraser does not get rid of the blue permanent marker on the board, antibiotics do not target or kill off the body cells or good bacteria (blue marker) that exists inside the body and keeps people healthy. Dry erasers do not target specific kinds of marker, but they are only effective for certain kinds of markers. Antibiotics work in a very similar way: they do not target certain kinds of bacteria, but are strategically effective in killing off only the bad kinds of bacteria without damaging good bacteria or body cells.

a. 1/10
b. Selective (1)
c. 162 Words