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Can "Less" Create "More" in Analogical Reasoning?

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Abstract

Successful analogical reasoning requires an analogue in a source domain to have high degrees of structural and surface similarity with a learning task in a target domain. It also requires learners to have sufficient source- and target-domain knowledge. We review the literature and speculate that “less” might create “more”; in some situations, analogies that have fewer degrees of similarity may be more effective for learning. In this exploratory study, we engaged eight school leaders in dyads to develop a bottom-up perspective on innovation diffusion through analogical reasoning. The qualitative data in the study appears to echo our speculation. The dyads that have less prior target-domain knowledge face challenges with regard to innovation diffusion when they learn with analogues that have more degrees of similarity – both structural and surface. They, however, are able to learn with analogues that have fewer degrees of similarity. Learning was shown to take place when the dyads reflected on an analogue first, before they compared the analogue and innovation diffusion to make any analogical inferences. Although constrained by the exploratory nature of the study, the findings provide preliminary evidence that “less” is possible to create “more” in analogical reasoning under certain conditions, implying an interesting direction for experimental examination in future.

Key Words: Analogical Reasoning, Degrees of Similarity, Prior Knowledge, Desirable Difficulties, Instruction

Introduction

Analogical reasoning occurs when learners use their knowledge of one particular concept to draw assumptions or interpretations about a different concept, provided they can recognize an analogy between the two differing concepts. The literature in analogical reasoning describes this as making use of a learner's knowledge in a "source domain" (i.e., the familiar concept) to learn knowledge in a "target domain" (i.e., the new concept) by making inferences analogically (Gentner & Holyoak, 1997).

Our work makes use of analogical reasoning to help school leaders (e.g., principals, heads of departments and officers of the Ministry of Education, etc.) learn to change their ways of implementing curricular innovations throughout schools. In particular, we show how analogy recognition can lead school leaders who typically use top-down strategies (such as mandating teachers to use a curricular innovation in their classes) to shift to bottom-up strategies (such as leveraging on word-of-mouth spreading of an innovation to influence teachers' voluntary adoption of the innovation). In this paper, we first cover the literature on analogical reasoning, then present findings from an analysis of how school leaders adopt bottom-up strategies through analogical reasoning, and finally share the implications for educational practice.

Conditions for successful analogical reasoning

The literature suggests that for successful analogical reasoning to take place: (a) the source and target should share more degrees of "structural" and "surface" similarity, (b) learners should have more prior source- and target-domain knowledge, and (c) instruction should promote compare-and-contrast between the source and target.

Structural and surface similarities

Based on the causal relevance to goal attainment in analogical reasoning, Holyoak and Koh (1987) distinguished similarities between the source and target domains as either "structural" or "surface". A structural similarity (e.g., matching of a relationship) is a similarity that plays a causal role in determining the possible solutions in the source and target domains, while a surface similarity (e.g., matching of a feature) refers to a similarity that does not influence such goal attainment. For example, consider *a truck towing a car* (scene 1) in comparison with *a car towing a boat* (scene 2). A structural similarity between scenes 1 and 2 would be "towing an object" (i.e. the *truck* in scene 1 and the *car* in scene 2 both tow something); while a surface similarity would be "car" (i.e. both scenes use the same type of vehicle).

With regard to structural similarities, the existing literature claims that for analogical reasoning to take place, learners need to recognize the structural similarities between the source and target domains (Gentner, 1983; Gick & Holyoak, 1980). Sander and Richard (2005) noted that the degree of analogical transfer (e.g., the mapping of a problem solution from the source domain to the target domain in a way that preserves the relationships between the interconnected structures in each domain) is proportional to the relative number

of structural similarities the source and target have in common. Gentner and colleagues also emphasized the importance of structural similarities in analogical transfer (see Gentner & Toupin, 1986).

With regard to surface similarities, existing work has shown that successful analogical reasoning also requires the source and target domain to have more degrees of similarity (Perkins & Salomon, 1992). Various other studies (Barnett & Ceci, 2002; Forsyth, 2012; Hakel & Halpern, 2005) have suggested that transfer rarely happens when analogies have fewer degrees of surface similarity. Chi and VanLehn (2012) proposed that this is perhaps because surface similarities give cues to learners in recognizing structural similarities.

Prior source- and target-domain knowledge

Successful analogical reasoning also requires learners to have more prior source- and target-domain knowledge. The basic assumption behind analogical reasoning is that when there are substantial parallels (e.g., structural similarities) across two different situations, there are likely to be further parallels (e.g., similarities in solution) (Gentner, 2003). However, there is no guarantee that the inferences on further parallels will be true. Thus, for learners to make inferences from an analogy, they need prior knowledge to evaluate the structural alignment and inferences (Braasch & Goldman, 2010). In other words, they must be able to align structural similarities so that the matches and inferences between source and target are based on the interconnected relational structure, rather than isolated matches.

With regard to prior source-domain knowledge, learners typically need more knowledge to evaluate analogical alignment and make inferences. Source-domain knowledge is also necessary for mapping to the target domain (Gentner & Holyoak, 1997). Smith and Unger's (1997) study suggested that when learners do not have a good grasp of the source domain, they may regress in their understanding of the source domain in the process of analogical reasoning.

With regard to prior target-domain knowledge, learners' lack of knowledge may also limit their evaluation of analogical alignment and inference-making (Bransford, Brown, & Cocking, 1999; Kole & Healy, 2007; Mozzer & Justi, 2012). For example, Schliemann and Magalhaes (1990) studied 28 female Brazilian cooks who did not receive formal mathematical instruction of proportions before, but knew how to solve price problems that involved proportional relations. Three problem-solving conditions were as follows: Group 1 participants were given recipe, price, additional recipe, and then medicine problems (in that order); Group 2 participants were given recipe, price, and then medicine problems; and Group 3 participants were given medicine, price, additional medicine, and then recipe problems. The researchers found that the participants were able to transfer proportional calculations from price to recipe problems, but had difficulty transferring to medicine problems, a totally unfamiliar domain. The study also found that when dealing with medicine problems, the participants tended to apply any kind of arithmetical transformation to the

given quantities and gave nonsensical responses that were never given to recipe problems. Thus, the lack of target domain knowledge hampered their inference-making.

Compare and contrast in instruction

Compare and contrast is important for analogical reasoning. Analogical encoding (Gentner, Loewenstein, & Thompson, 2003) and analogical bootstrapping (Kurtz, Miao, & Gentner, 2001; Smith & Unger, 1997) are two instructional strategies that have been shown to promote analogical reasoning. In analogical encoding, learners compare two exemplars to identify their similarities in order to make the common relational structure between the two exemplars more salient. Analogical bootstrapping is the process of using structural understandings in one domain to guide the restructuring of a set of concepts in another domain (via analogy). Analogical encoding and analogical bootstrapping both seek to compare and contrast the source and target domains to promote analogical reasoning and transfer (Marton, 2006; Watson & Mason, 2005). Marton (2006) showed that sameness between the two domains can be better discerned by contrasting their differences. Thus, comparing and contrasting between source and target can promote explicit mappings of the similarities in analogical reasoning.

In general, the literature suggests that more degrees of similarity and more prior knowledge between source and target domains lead to better analogical reasoning and transfer. While we do not discount the few decades of literature on analogical reasoning, we speculate whether fewer degrees of similarity and less prior knowledge might also induce successful analogical reasoning, especially in more naturalistic contexts than laboratory experiments. We first provide reasons to justify this speculation, and then present the findings of our work that support our conjecture.

Our speculation: Can "less" create "more" in analogical reasoning?

There are four considerations on which we base the speculation of whether fewer degrees of similarity and less prior knowledge may also induce successful analogical reasoning under certain situations. First, Reed's (2012) extensive review of transfer literature showed that one-to-one structural mappings (e.g. more degrees of structural similarity) were not always better than partial structural mappings (e.g. fewer degrees of structural similarity) in analogical reasoning. However, Reed did not compare surface similarity in his review, which may partially account for the discrepancy (i.e., more degrees of structural similarity were not always better). We suspect that surface similarity may not fully account for the discrepancy.

Second, in retrospective transfer (Marton, 2006), when learners try to solve a problem in a target domain, they might activate their prior knowledge of solving a problem from a source domain (of which they are familiar) to help them solve the target problem. This suggests that when the source and target domains share more degrees of structural and surface similarity, they are likely to be of similar cases in the same domain. This creates a

challenge when learners do not have sufficient prior source-domain knowledge that is necessary for them to analogically map to the target domain, leaving learners unable to then solve the target problem.

Third, we feel that requiring learners to have good prior target-domain knowledge may create a dilemma between the goal and the conditions for successful analogical transfer. Learners are able to learn through analogues possibly because they initially understand the source and target domains in dissimilar ways (Smith & Unger, 1997). Reeves and Weisberg (1994) argued that if one already perceives the structural aspect of a target situation, further mapping of it to another situation would seem unnecessary, because recognizing that a particular relationship exists between the target and source domains is equivalent to finding the solution or understanding (Wong, 1993). Wagner (2006) also purported that perceiving two situations as analogically similar because we recognize them as sharing the same structure may well be tautological.

A fourth consideration is based on some counterintuitive findings reported in the literature from impasse driven learning. For example, Kapur (2006, 2008, 2012, 2013, 2014) engaged students in their studies to solve ill-structured problems. They found that instead of providing immediate structure to scaffold learning, it was more productive to delay the scaffolding until students reached a form of failure. These examples contrast more traditional notions (Schwartz, Lin, Brophy, & Bransford, 1999) that students need scaffolding at the start of a learning task to regulate their cognitive load that is demanded by a difficult learning task. Bjork and Bjork (2011) argued that the counterintuitive findings are because of *desirable difficulties* in learning. Such difficulties, while appearing to impede performance during training, yield greater learning benefits later.

Thus, the questions through which we frame our work are as follows:

- Do such *desirable difficulties* exist in analogical reasoning?
- Can fewer degrees of similarity – both structural and surface – produce better analogical reasoning under certain conditions?
- How do learners engage in analogical reasoning when they have less target-domain knowledge?

Research Context and Method

Although our claims about the conditions that make analogical reasoning more likely are speculative, we present our work providing initial evidence that suggests future research directions. The study was conducted in the form of exploratory case studies (Stake, 2013; Yin, 2013) focusing on using analogical reasoning to shift school leaders' perspectives on innovation diffusion (i.e., how to increase the adoption of curricular innovations in their schools).

Innovation diffusion as the subject domain

The study was to help school leaders learn the concept of innovation diffusion. Rogers (2003) regarded innovation diffusion as a process in which an innovation is communicated

and adopted over time among members of a social system, for example in a school. Rogers emphasized the need to persuade individuals for innovation adoption and highlighted the importance of the sharing and spreading of opinions among members in social interactions, e.g., through word-of-mouth communication. Rogers' definition represents a bottom-up perspective on innovation diffusion.

Scholars (Carr Jr., 1999; Looi, Lim, Koh, & Hung, 2005) have noted that school leaders tend to use top-down strategies to mandate the implementation of curricular innovations. Fullan (1994, 2007) observed that these top-down strategies consistently fail to achieve sustainable diffusion. When teachers are mandated to use such innovations, they are likely to produce and share negative opinions in social interactions with their peers (Rogers, 2003). Thus, the purpose of our study was to help school leaders to develop a complementary bottom-up perspective on innovation diffusion. For example, school leaders can effectively engage teachers who are "pro-innovation" and have good social connections with their peers to spread the innovation through word-of-mouth communication.

To develop a bottom-up perspective, school leaders need to understand and adopt at least two key notions: (1) teachers' decision-making is with limited rationality and can be largely influenced by other teachers' opinions; and (2) opinions are best shared through word-of-mouth communication among teachers connected in social networks. These two notions are strongly underscored in Rogers' well-cited work *Diffusion of Innovation* (Rogers, 2003).

Table 1 contrasts the two notions and their correspondences to the top-down perspective. The need to learn these two notions allows us to use analogues that have structural similarities to one or both notions to explore our claims.

Table 1
Two notions as the learning objectives

Notions	Prior knowledge (Top-down perspective)	Learning objectives (Bottom-up perspective)
Notion 1 (Decision-making)	Teachers' decision-making is fully rational. Teachers will adopt an innovation if they know the benefit of the innovation.	*Teachers' decision-making is with limited rationality (Gigerenzer & Selten, 2002) and can be largely influenced by other teachers' opinions.*
Notion 2 (Communication)	Communication by school leaders directly to teachers is most effective. Peer level social interactions have minimum impact.	*Opinions are best shared through word-of-mouth communication among teachers connected in social networks (Rogers, 2003).*

Research study and participants

Four case studies were conducted and each case involved two school leaders from the same school or the Ministry of Education (MOE). The participants in each dyad case learned together in a meeting room of their respective organization (i.e., schools or MOE). The contexts are presented in Table 2.

Table 2
The contexts of the four cases

Case	One	Two	Three	Four
Participant 1	Principal (C1P1)	Vice Principal (C2P1)	Head of ICT (C3P1)	Ed-Tech Officer (C4P1)
Participant 2	ICT mentor (C1P2)	Head of Science (C2P2)	Assistant Head/ ICT (C3P2)	Ed-Tech Officer (C4P2)
Organization	Secondary School	Primary School	Primary School	MOE
Curricular Innovation	iPad for learning	Holistic assessment	Design pedagogy	Pedagogical innovation
Approach to Implement Innovation	Volunteer teachers are trained (i.e., voluntarily adopt)	All teachers are mandated by school leader (i.e., mandate to adopt)	Mandate to adopt	Mandate to adopt

In the study, two participants in each dyad case learned together with the first author's facilitation. They were first engaged in an activity to build and simulate a computer model on innovation diffusion, and then were given analogues to reflect upon.

The first author facilitated each dyad to reflect in a conversational style. He prompted the participants to compare between the analogue and innovation diffusion or introduced a new analogue for them to reflect upon when they could not find the current analogue useful (i.e., not being able to identify the analogy). Analogical encoding (Gentner et al., 2003) was not explicitly promoted. No predetermined list of questions was used in the facilitation. Across the cases, the dyads conceptualized the bottom-up perspective of innovation diffusion through analogical reasoning.

A detailed description of the design for analogical reasoning is presented below.

Categorization of analogues

Across the cases, six analogues[1] were given to the dyad throughout the learning activity: spreading of rumor, persuading smokers to quit smoking (in short, quit smoking), virus infection, spreading of DVORAK keyboard, spreading of iPhone, and evangelizing.

Based on the analogues' degrees of structural and surface similarity with innovation diffusion, we categorized the analogues into three types (Table 3). For easy referencing, we refer to analogues with more degrees of structural and surface similarity as Analogue MM, those with more degrees of structural similarity and fewer degrees of surface similarity as Analogue MF, and analogues with fewer degrees of structural and surface similarity as Analogue FF.

Table 3
Categorization of analogies by degrees of similarity to innovation diffusion

		Degrees of surface similarity	
		More	Fewer
Degrees of structural similarity	More	***Analogue MM*** (*Spreading of iPhone*) (*Spreading of DVORAK keyboard*)	***Analogue MF*** (*Spreading of rumor*) (*Evangelizing*)
	Fewer	***Analogue FM*** NA[2]	***Analogue FF*** (Q*uit smoking*) (*Virus infection*)

The classification of the degrees of structural similarity is based on the analogues' structural mappings with regard to the two notions to be learned (i.e., teachers' decision-making is with limited rationality and can be largely influenced by other teachers' opinions; and opinions are best shared through word-of-mouth communication among teachers connected in social networks).

The analogues' structural mappings to innovation diffusion are summarized in Table 4. For example, the spreading of rumor analogue is an example of Analogue MF. A person who hears a rumor has to make the decision (with limited rationality) whether or not to believe the rumor (i.e., notion 1 of the bottom-up perspective). The rumor spreads as people share with their friends in social networks (i.e., notion 2 of the bottom-up perspective). Thus, the spreading of rumor analogue has structural mappings to both notions.

[1] The Case One dyad did not receive the quit smoking, virus infection and evangelizing analogues. Reasons are provided later in this paper.

[2] To use an Analogue FM would be, for example, to keep the quit smoking analogue within the school context. We deemed it unnecessary to include this type of analogue in our design because the participants might not have such lived experience (within their school context).

In contrast, in the virus infection analogue (Analogue FF), a virus spreads as people interact with each other in social networks (i.e., notion 2 of the bottom-up perspective). However, a person who is exposed to a virus does not have the autonomy to choose whether to be infected (i.e., no correspondence to notion 1 of the bottom-up perspective). Thus, the virus infection analogue has structural mapping to notion 2 only.

Table 4
Analogues' structural mappings to the two notions of innovation diffusion

	Structural mappings	
Analogues	Decision-making in adoption (Notion 1)	Communication for diffusion (Notion 2)
Analogue MM		
Spreading of iPhone	X	X
Spreading of DVORAK keyboard	X	X
Analogue MF		
Spreading of rumor	X	X
Evangelizing	X	X
Analogue FF		
Quit smoking	X	
Virus infection		X

Design of the sequence

Analogues were given to the dyads in the sequence of Analogue MM, MF and FF. This sequence allowed us to identify whether the participants who did not learn from analogues that have more degrees of similarity indeed learned with analogues that have fewer degrees of similarity.

In this study, if a dyad could not establish analogical mapping between the source and target, the researcher would facilitate the dyad to reflect on the analogue. This strategy was informed by Smith and Unger's (1997) suggestion that for successful analogical reasoning to take place, "it is wise to ensure strong understanding of the source domain first" (p. 174). If a dyad learned successfully with an analogue (e.g. Analogue MF), the next type of analogue (e.g. Analogue FF) was not given to the dyad. For example, as the Case One dyad learned with analogue MF (i.e., the spreading of rumor analogue), analogues FF was not given to the dyad.

Data analysis

The data analysis used the dyad as the unit of analysis. This is because the two participants in each dyad case learned together, and they rarely challenged each other's views during the learning activity. Most of the time, they either agreed with each other in silence (based on the interpretation of their facial expression in video data and the consistency of their views in the discourse) or they built upon each other's view (e.g., by providing examples or make deeper reflection on each other's view).

The analysis was conducted by examining the transcriptions of each dyad's spoken reflections throughout the process of the learning activity. For each dyad, the transcription was first chunked into episodes. Each episode started when a dyad was facilitated by the researcher to start a new topic and ended when the dyad moved on to talk about a different topic. For example, when a dyad that was talking about the factors teachers consider when deciding to adopt an innovation made a switch to talk about the stages of teachers' decision making, this demarked the end of one episode, and beginning of the next episode.

All episodes that involved analogical reasoning were included for further analysis, leading to a total of 14 episodes. Each episode was first coded in four aspects: the case number, the sequence of occurrence (i.e., first, second, third or fourth analogue given to the dyad), the type of analogue given (i.e., Analogue MM, MF or FF), and whether the analogical reasoning was successful. For example, C2-1-MM-U refers to the Case Two (C2) dyad's first (1) analogical reasoning episode. The reasoning was with Analogue MM (MM) and the dyad was unsuccessful (U) in analogical reasoning.

The successful and unsuccessful analogical reasoning episodes were compared and contrasted using a Grounded Theory (Charmaz, 2000) approach to identify the patterns. The inter-rater reliability was 91%. The reliability was computed based on the percentage of common codes that were coded by two independent raters using an emerging coding scheme developed from ground up. All coding differences were then resolved through discussions.

The Case One dyad had more prior target domain knowledge as compared to other dyads. First, C1P1 self-reported that he had done casual reading on *system thinking* articles that mentioned the bottom-up perspective of systems. Second, the Case One dyad did not use mandate as an approach for diffusion. As shown in Table 2, while other dyads mandated all teachers to use the innovation, the Case One dyad encouraged teachers to voluntarily join a core group (i.e., adopters' group) and then provided training and support to the core group. The limitation of using these two criteria to assess the dyads' prior knowledge is discussed later.

Findings

The 14 analogical reasoning episodes are summarized in Table 5 below. The data analysis echoes our speculation that "less" is possible to create "more" in analogical reasoning.

Table 5
The fourteen analogical reasoning episodes

Episodes	Case One	Case Two	Case Three	Case Four
First analogical reasoning episode	C1-1-MM-U Analogue MM *(Spreading of DVORAK keyboard)* Unsuccessful	C2-1-MM-U Analogue MM *(Spreading of DVORAK keyboard)* Unsuccessful	C3-1-MM-U Analogue MM *(Spread of iPhone)* Unsuccessful	C4-1-MM-U Analogue MM *(Spread of iPhone)* Unsuccessful
Second analogical reasoning episode	C1-2-MF-S Analogue MF *(Spreading of rumor)* Successful	C2-2-MF-U Analogue MF *(Spreading of rumor)* Unsuccessful	C3-2-MF-U Analogue MF *(Spreading of rumor)* Unsuccessful	C4-2-MF-U Analogue MF *(Evangelizing)* Unsuccessful
Third analogical reasoning episode	-	C2-3-FF-U Analogue FF *(Virus infection)* Unsuccessful	C3-3-FF-U Analogue FF *(Virus infection)* Unsuccessful	C4-3-FF-U Analogue FF *(Quit smoking)* Unsuccessful
Fourth analogical reasoning episode	-	C2-4-FF-S Analogue FF *(Virus infection)* Successful	C3-4-FF-S Analogue FF *(Quit smoking)* Successful	C4-4-FF-S Analogue FF *(Virus infection)* Successful

Three patterns were identified in the data analysis: (a) across the cases, the dyads did not learn with Analogue MM (C2-1-MM-U as an example); (b) the Case One dyad who had more prior target-domain knowledge learned with Analogue MF (in C1-2-MF-S); (c1) Cases Two, Three, and Four dyads who had less prior target-domain knowledge did not learn with Analogy MF (e.g., in C3-2-MF-U), but (c2) learned with Analogue FF (e.g., in C3-4-FF-S) only after they were engaged to reflect on their source-domain knowledge first (e.g., the comparison between C3-3-FF-U and C3-4-FF-S). These patterns are further elaborated below.

Pattern a: Failure in learning with Analogy

As we speculated, when the analogue (i.e., Analogue MM) had high degrees of structural and surface similarity with innovation diffusion, the dyads did not have sufficient prior knowledge (i.e. of notions 1 and 2) on the analogue (i.e., the source) which is necessary for them to map to learn innovation diffusion (i.e., the target). This corresponds with our speculation concerning retrospective transfer. Excerpt 1 is extracted from Episode C2-1-MM-

U as a demonstrating example. In the episode, the researcher shared the diffusion of the DVORAK keyboard as an analogue (i.e., Analogue MM): the DVORAK keyboard is more efficient than the QWERTY keyboard, but the diffusion of the DVORAK keyboard was not successful. The participants immediately acknowledged the analogy between the spreading of DVORAK keyboard and the innovation diffusion in school. In Excerpt 1, the researcher facilitated the dyad to identify knowledge on the diffusion of the DVORAK keyboard (i.e., the analogue) for mapping to learn innovation diffusion, but the dyad did not activate prior knowledge on the analogue that correspond to notions 1 and 2.

Excerpt 1 (C2-1-MM-U):

R (Researcher): Assuming you are the manager from the company that sells the DVORAK keyboard. What strategy would you want to play to diffuse it in Singapore?
C2P1: I don't know. If I know, I will be great.
C2P2: I have no idea what I would do because people have been so used to that (QWERTY) type of typing and it became a habit.
R: How to change people's habit?
C2P2: It is very difficult.
R: How do you change your own habit?
C2P2: When I know why a habit is bad for me, I will just change, at least make an effort to change.
R: Besides your experience in diffusing innovation in schools, is there any other successful diffusion cases you can learn and apply here?
C2P1: (It is) (t)o convince people and show that the innovation is an alternative. Tutorial allows people to follow, do and learn. I am assuming that there is a tutorial available for this new keyboard.
R: So it is like providing information and training to people?
C2P1: Yes.

The excerpt suggests that the dyad either did not have a bottom-up perspective on Analogue MM for mapping (e.g., "*I don't know. If I know, I will be great.*"), or they only activated knowledge that was consistent with their top-down perspective (e.g., "*I am assuming that there is a tutorial available for this new keyboard.*"). The understandings on limited rationality (i.e., notion 1) and spreading through social networks (i.e., notion 2) were absent.

Patterns b and c1: Success and failure in learning with Analogue MF

The data suggests that the dyad that had more prior target-domain knowledge learned with analogues that have more degrees of structural similarity and fewer degrees of surface similarity (i.e., Analogue MF) (pattern b), but the dyads that had less prior target-domain knowledge did not (pattern c1). The respective examples are provided below for illumination.

Pattern b: The Case One dyad's success in learning with Analogue MF

In Episode C1-2-MF-S, the spreading of rumors analogue (i.e., Analogue MF) was given to the Case One dyad. The dyad spontaneously recognized the similarities between the analogue and innovation diffusion. They also generated their own analogies and learned notion 2 for innovation diffusion. Excerpts 2 – 4 below are extracted from the episode.

Excerpt 2 (C1-2-MF-S):

R: How is innovation diffusion similar or different from the spreading of rumors?

C1P1: (In our strategy,) (t)he core group people are building up, but it is the sharing that diffuses the innovation. Innovation diffusion and spreading of rumor are all about spreading.

In Excerpt 2, when the dyad was asked to compare innovation diffusion and the spreading of rumor analogue, they quickly aligned their knowledge in the target domain (e.g., "*it is the sharing that diffuses the innovation*") and spontaneously realized the similarity between the source and target (e.g., "*all about spreading*"). This understanding corresponds with notion 2 (i.e., spreading through social networks).

The researcher then challenged the dyad for the differences between their knowledge of Analogue MF and innovation diffusion (see Excerpt 3).

Excerpt 3 (C1-2-MF-S):

R: To diffuse innovation, you organize school wide ICT sharing sessions and get all the teachers to attend. But in spreading of rumor, no formal meeting is arranged and yet the rumor spreads to almost everyone.

After five seconds of silence…

C1P1: (Spreading of rumor is like a) (k)ind of virus infection. One person passes to another then passes to another. So should that be considered (in our innovation diffusion)?

R: Have you seen this kind of spreading in your diffusion of innovation?

C1P2: I have not officially started talking about the innovation. When people saw me carrying iPad, some of them came up to me and asked me how I used it (for teaching). I talked to people about it and I showed them stuff. It did spread a bit. Before we actually start (forming the core group), I am actually working on the ground already.

In Excerpt 3, when the dyad was comparing the knowledge in the source and target domains, C1P1 spontaneously generated his own analogue (i.e., virus infection, Analogue FF) as a bridge to connect Analogue MF and innovation diffusion.

Subsequently, in Excerpt 4 C1P1 generated another analogue (i.e., evangelizing, Analogue MF) for innovation diffusion.

Excerpt 4 (C1-2-MF-S):

C1P1: So what kind of strategies can we put in place to generate that kind of spreading?

C1P2: But sometimes people just trigger (the sharing). You're tapping on human nature (to share).

After five seconds of silence…

C1P1: I want the core group to "*evangelize*" and to reach out to other people. I think we can encourage them to be more open to share.

R: How do you want to make it happen?

C1P1: (I am) (t)hinking about the staff lounge. I don't know how feasible it is. Maybe we can just put a few iPads there.

C1P2: We can put them there and whoever is there can just pick up one and see how it can be used. It is human nature to be curious.

C1P1: People can talk about it among themselves. That is a way to spread the "*rumor*".

Encouraging adopters (i.e., those in the core group) to "*evangelize*" to others and putting iPads at the staff lounge to generate sharing among teachers suggest that the dyad developed initial understanding of notions 1 and 2 (i.e., teachers have limitation rationality and they can be influenced by peers in social interactions).

Excerpts 2 – 4 suggest that successful analogical reasoning took place when the dyad regarded the analogue and innovation diffusion to be similar. Challenging the dyad's knowledge differences in the source and target domains led to the dyad's mapping of their knowledge from the source domain (i.e., spreading rumor by one passes to another) to the target domain (i.e., innovation is diffused when teachers spread it among themselves, which is notion 2 in Table 4).

Pattern c1: The Cases Two, Three and Four dyads' failure in learning with Analogue MF

Contrary to Case One, the data from the Cases Two, Three, and Four suggests that when the dyad lacked prior target-domain knowledge, they tended to see the analogue and innovation diffusion as different, and therefore did not learn with Analogue MF.

Excerpt 5 extracted from Case Three and Excerpt 6 extracted from Case Four are provided for illustrative purposes. In Excerpt 5, the researcher asked the dyad directly to compare innovation diffusion and the spreading of rumor analogue (i.e., an Analogue MF).

Excerpt 5 (C3-2-MF-U):

R: How is innovation diffusion similar or different from the spreading of rumor?

C3P1: It is easy to spread rumor, but it is not easy to carry out innovation.
C3P2: There is no consequence attached to rumor when people adopt it. But for innovation, once a teacher adopts it, much work has to be done (by the teacher). There are consequences to face.
R: What do innovation diffusion and the spreading of rumor have in common?
C3P1: In spreading of rumor, people have that curiosity, which needs to be addressed (/satisfied).
R: Is there curiosity in innovation diffusion?
C3P1: We are able to create the curiosity if the innovation is novel. As Robotics (i.e., the design pedagogy diffused in the school) has been in this school for some time, there is no longer novelty.

In the above excerpt, when the researcher gave an explicit cue for the dyad to focus on the similarities between Analogue MF and innovation diffusion, the dyad did mention one similarity (i.e., people's curiosity on rumor/innovation). However, the dyad continued to differentiate the source and target by emphasizing the difference, "*As Robotics has been in this school for some time, there is no longer novelty*". As the dyad did not recognize the analogy, learning through analogical reasoning was not successful.

Excerpt 6 (extracted from C4-2-MF-U) below suggests that when asked to compare the evangelizing analogue (Analogue MF) and innovation diffusion, the Case Four dyad also focused on the differences.

Excerpt 6 (C4-2-MF-U):

R: What are the similarities and differences between evangelizing and diffusing innovation?
C4P1: Evangelizing is very personal. Diffusing innovation is part of the work.
R: How do you evangelize to others?
C4P2: I try to share my testimonials with people and try to convince them.
R: What are testimonials?
C4P2: These are my encounter with God. How God helped me at difficult times.
R: Why sharing personal testimonials is important?
C4P2: Personal testimonials are facts. People cannot deny.
R: What about diffusing innovation?
C4P2: It is different. Teachers may feel that it (i.e., the message about the innovation) is sugar-coated by school leaders.
R: Would people being evangelized feel that you sugar-coat your experience?

C4P2: That's why evangelizing is difficult. You need to spend a lot of time to work on people. In schools (when diffusing innovation), time is a luxury.

When the researcher facilitated the dyad to reflect on the analogue (e.g., "*how do you evangelize to others*?"), C4P2 mentioned that sharing personal experience was important in evangelizing. This notion could have potentially been mapped for the dyad to learn innovation diffusion. However, C4P2 continued to emphasize on the differences between the analogue and innovation diffusion: when evangelizing, you "*need to spend a lot of time to work on people"*, but when diffusing innovation in schools, *"time is a luxury,"* thus failing to recognize the analogy.

Pattern c2: Success in learning with Analogue FF

When the Cases Two, Three, and Four dyads were learning with Analogue FF, they also tended to focus on the differences between the analogues and innovation diffusion. As the researcher facilitated the dyads to reflect on the analogue, the dyads in all cases then spontaneously recognized the similarities between Analogue FF and innovation diffusion. They were able to successfully map their knowledge through the analogy to learn the notions for innovation diffusion.

Excerpt 7 extracted from C3-3-FF-U is provided below to show that the Case Three dyad focused on the differences between the source and target. Excerpts 8 – 10 (extracted from C3-4-FF-S) are then provided to illustrate how the successful learning took place when the Case Three dyad was facilitated to reflect on analogue first.

Excerpt 7 shows that when the Case Three dyad was facilitated to compare innovation diffusion and the virus infection analogue (i.e., an Analogue FF), the dyad focused on the differences between the source and target, a pattern that was similar to Excerpts 5 and 6.

Excerpt 7 (C3-3-FF-U):

R: How is innovation diffusion similar or different from virus infection?

C3P1: In virus infection, once you are in contact with a sick person, you will get infected. The infection is beyond your control. But in innovation diffusion, you have a choice to choose to adopt or not. If you choose to adopt, you will have to put in a lot of effort to implement it in your classroom.

Learning through analogy was not successful in this episode when the dyad only focused on the differences between the source and target (e.g., "*The infection is beyond your control. But in innovation diffusion, you have a choice to choose to adopt or not*"). Excerpts 5-7 were rather short, because the dyads had nothing else to offer when they focused on the differences. These examples suggest that when the dyads only focused on the differences

between the analogue and innovation diffusion, it was easy for them to stop analogical reasoning because analogical reasoning requires a focus on similarities.

The Cases Two, Three, and Four dyads overcame the challenge when their analogical reasoning was facilitated in three steps: reflect on the analogue first, map back and forth between the analogue and innovation diffusion for analogy recognition, and then activate prior experience on the analogue for mapping to learn innovation diffusion.

Excerpts 8 – 10 (extracted from Episode C3-4-FF-S) illustrate these steps. The researcher facilitated the dyad to reflect on the quit smoking analogue (i.e., Analogue FF) and then facilitated the mapping between innovation diffusion and the analogue.

Excerpt 8 (C3-4-FF-S):

R: Now there is a smoker. We can show him why smoking is bad to his health, or show him the cases that other smokers die because of cancer. Would this smoker respond to the two messages in the same way?

C3P1: The buy-in would be stronger when you show the cases of people die because of smoking.

R: Why?

C3P2: Being human beings, we are keen to know how we can benefit from this. So apart from just showing the rationale, its advantages should also be laid down so to concretize what is being said.

In the excerpt, the dyad reflected on the analogue (e.g., "*the buy-in would be stronger when you show the cases of people die because of smoking*") and activated her prior knowledge (e.g., "*apart from just showing the rationale, its advantages should also be laid down so to concretize what is being said*"). After the activation of suitable prior knowledge, the dyad was then facilitated to map back and forth between Analogue FF and innovation diffusion (see Excerpt 9 below), and the dyad finally recognized that the analogue and innovation diffusion were similar.

Excerpt 9 (C3-4-FF-S):

R: What if you mandate teachers to adopt innovation?

C3P1: I think if you provide sufficient resources, it should not be too much. There should not be too many objections. For example, I know that in this reading programme, the books and resources are there; how to teach it is there; the guides are also provided. You (teachers) just have to follow it accordingly. To me, I do not see it as being very difficult to do and carry out the innovation.

R: If we compare this to a "*Stop Smoking*" campaign, if, for example, the government mandate that all smokers give up smoking. How will people respond?

C3P2: Resistance; they will fight back. It is their right to smoke.

R: But the government has shown the people why smoking is bad. It provides the support and resources to help people give up smoking.
C3P2: But there is no buy-in. They (smokers) will smuggle.
R: How about when we mandate teachers adopt innovation?
C3P2: Oh. I am not sure. Maybe they don't have buy-in either. (After three seconds of silence,) (s)o the "*innovation*" is "*quit smoking*", right?

The last question asked by C3P2 suggests that she mapped "*innovation*" to the "*quit smoking message*" and recognized that persuading a smoker to quit smoking is similar to diffusing innovation among teachers. Recognizing the analogy led to C3P1's activation of prior experience on Analogue FF for mapping to learn innovation diffusion (see Excerpt 10 below).

Excerpt 10 (C3-4-FF-S):

R: So how can you create buy-in in your school?
C3P1: (In the quit smoking campaign, the) (g)overnment requires warning be printed on the cigarette packaging (...)
C3P2: It may not work. Perhaps people (smokers) just want to look cool and it is their lifestyle choice.
R: Do you see many successful cases that people give up smoking?
C3P1: I watched a movie. A son and his father were very close to each other and they were both smokers. The son saw his father passed away because of lung cancer and he gave up smoking as a promise to his father.
C3P2: So we cannot address the smoking problem at the logical level. We can show them (i.e., smokers) how their loved ones may suffer (if they continue smoking). If such things are shared by their smoker relatives or friends, it will be close to their heart.
C3P1: We can do the same. We can show teachers the successful cases in using innovation.

In the excerpt, C3P2 noted that "*we cannot address the smoking problem at the logical level*" and "*if (how their loved ones may suffer from their smoking) are shared by their smoker relatives or friends, it will be close to their heart*". This is similar to notion 1 (e.g., limited rationality in teachers' decision making) in the learning goal. C3P1 then mapped it analogously to innovation diffusion: "*We can do the same (for innovation diffusion).*"

Excerpts 8-10 (in which the dyad learned successfully) and Excerpt 7 (in which the same dyad failed to learn) involved the same dyad (i.e., the Case Three dyad) learning from the same type of analogue (i.e., Analogue FF). A critical difference between the success and

failure is whether the dyads were facilitated to compare the analogue and innovation diffusion first (as in Excerpt 7) or to reflect on the analogue first (as in Excerpt 8).

The three patterns presented above support our speculation that "less" is possible to create "more" in analogical reasoning. These patterns tentatively suggest that simply asking the dyads to compare the analogues and innovation diffusion might not help analogical reasoning (as shown in Excerpts 5, 6 and 7). Facilitating the dyads to reflect on an analogue first appeared to be effective for learning with analogues that have fewer degrees of surface and structural similarity (as shown in Excerpts 8-10), but not for learning with analogues that have more degrees of similarity (as shown in Excerpt 6).

Conclusion and Discussion

This study was conducted to help school leaders to use analogical reasoning to learn a bottom-up perspective regarding innovation diffusion (i.e., the two notions: teachers' decision-making is with limited rationality and can be largely influenced by other teachers' opinions; and opinions are best shared through word-of-mouth communication among teachers connected in social networks). The sequence in which we presented the analogues to our participants allowed us to explore the speculation that "less" is "more." In other words, the dyads that had less prior target-domain knowledge learned with analogues that had fewer degrees of structural and surface similarity, but not with analogues that had more degrees of similarity.

Given that the generalizability of the findings is constrained by the exploratory nature of the study, the findings are not to refute the literature regarding the conditions for successful analogical reasoning. The study only demonstrates a possible alternative to the existing literature: "Less", meaning fewer degrees of structural and surface similarity between the source and target combined with less prior knowledge, is possible to create "more," meaning that learning can occur in analogical reasoning under certain conditions. For the purpose of informing future studies, discussions regarding analogues and instructional strategies are presented below.

Discussion with regard to analogues

The findings from this exploratory study support our speculation that learning with analogues that have fewer degrees of similarity might be a *desirable difficulty* (Bjork & Bjork, 2011). Kapur's work on Productive Failure (Kapur, 2008, 2014; Kapur & Bielaczyc, 2012; Kapur & Rummel, 2012; Kapur, Voiklis, & Kinzer, 2005) suggests that students dealing with *desirable difficulty* (for example, solving ill-structured problems without scaffolding) experience cognitive processes such as the exploration of a problem space and the differentiation of prior knowledge, which contribute to learning. In this study, the dyads' reflection on Analogue FF might have led to similar processes, which contributed to their learning with Analogue FF.

The study also suggests that when learners are facilitated to reflect on analogies with fewer surface and structural similarities (e.g. Analogue FF), they may recognize on their own

that the source and target are similar. It seems that our dyads spontaneously recognized that the source and target were similar, and thereafter drew the structural mappings accordingly. Their learning was not achieved by first establishing the structural mappings between the source and target. This finding is supported by Wilbers and Duit's (2006) argument of heuristic analogies: when scientists deal with unknown phenomena, they often generate analogies through global heuristic analogy-association, rather than the mapping of similarities.

The findings may also be interpreted differently with regard to the analogues. For example, the virus infection and the quit smoking analogues (Analogue FF) may have been more salient for the dyads than the spreading of rumor and the evangelizing analogues (Analogue MF). It is possible the participants might have had recent experiences in persuading someone to give up smoking, or contracting a virus. If this were the case, we would have seen the Cases Two, Three, and Four dyads (or at least one of these dyads) spontaneously recognizing the similarities between Analogue FF and the target before they were facilitated to reflect on the analogues. Nevertheless, the possibility of salience in analogue/s could be further examined in the future.

Discussion with regard to instructional strategies

This exploratory study may also inform how to use analogical reasoning to teach concepts. When the Cases Two, Three, and Four dyads were asked to make comparisons between the analogues (i.e., Analogue MF and Analogue FF) and innovation diffusion, they did not recognize the similarities between the source and target. This aligns with Gentner, et al.'s (2003) finding that simply asking learners to compare the source and target is less effective, for example, than guiding analogical encoding (i.e., it is more effective to use analogy to teach by guiding learners' analogical encoding to map and align structural similarities between the source and target).

Another way that analogy might be used to teach is through facilitating learners' reflection on the source domain first as a complementary strategy to analogical encoding. While Gentner, et al. (2003) found that simply presenting the source and target does not lead to spontaneous analogy recognition, Smith and Unger (1997) suggested that spontaneous bootstrapping (i.e., using structural understanding in one domain to guide the restructuring of a set of concepts in another domain) is possible to occur for certain analogues and with certain learners. Our study shows that spontaneous analogical transfer took place either when the dyads had more prior target-domain knowledge (in Case One when learning with Analogue MF) or when they reflected on the analogue first (in Cases Two, Three, and Four after the dyads were facilitated to reflect on Analogue FF to activate their relevant source-domain knowledge), supporting Smith and Unger's suggestion.

Limitations and Future Research

The findings should be interpreted under three main limitations. First, the participants' analogical reasoning could be partially explained by the model building activity. However,

we did not have sufficient data to check this because when the dyads were reflecting on an analogue, they did not refer to the model building activity. Instead, we assume that because the model building activity was not mentioned by any of the participants during their reflections on the analogues, it is likely that it was not as critical to their learning as the facilitation by the researcher reported in this paper. Second, as an exploratory case study, the findings cannot be further generalized. Third, the study did not measure the dyads' prior knowledge by systematically differentiating their target and source knowledge. Thus, we could not check whether the variation of the dyads' prior knowledge around the analogues was a contributing factor to our findings.

Despite these limitations, the study suggests interesting directions for future studies, upon which we are currently embarking. The first is to conduct experimental studies that test the three types of analogies among participants with varied prior knowledge in the source and target domains. Doing this may better substantiate our findings, and also provide both qualitative and quantitative data to more rigorously examine the learning processes involved in analogical reasoning. Secondly, the learning mechanisms underpinning analogical reasoning, especially the heuristic analogy-association, could be more strategically investigated towards contributing to the understanding of *desirable difficulties* in analogical reasoning.

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