Developing Independent Learners Through Metacognition

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Abstract

Students must be able to direct their own learning to succeed in college, career, and life. As have many researchers studying high school and college populations, I found this capacity lacking in my 11th and 12th grade AP Psychology students. One recurring piece of evidence was that students regularly construct incomplete mental models, often distracted by superficial elements of examples that instantiate a concept instead of focusing on the core structure underlying the examples. This impairs effective analogical transfer, which relies on complete mental models. While such distraction betrays the pervasive gap in students' metacognitive capacities, studies show that metacognition can be learned effectively through explicit teaching. Two metacognitive strategies stand out as successful in inducing mental models and facilitating enduring analogical transfer: similarity identification between analogous examples (SI), and self-explaining the new process as one learns (SE). In order to address the challenged described above, my intervention sought to combine SI and SE to enable students to develop and maintain mental models and analogical transfer that were both more complete and more enduring. The intervention focused on both applying these two metacognitive strategies as well as teaching students how to use them to help them develop their capacity as independent learners. The results reveal correlations supportive of the belief that both SI and SE facilitate enduring learning, though a small sample size limited the scope of the intervention and warrants further investigation into the strategies' combination. The analysis also sparked further questions of ways to improve students' identification of the essential components of their own thoughts and explanations.

Problem of Practice

I teach at Envision Academy of Arts and Technology (EA), a public charter high school in Oakland, because of its dedication to transforming students' lives by preparing them for success in college and in life. EA is one of three Envision Schools run by Envision Education, a nonprofit founded in 2002. The Envision Schools have clear mastery goals for their graduates, as well as a thoroughly scaffolded program for developing them. However, EA's mostly Latino and African-American students also demonstrate wide ranges of academic proficiency and often fall below grade level standards in reading, writing, and math.

For many EA students, this means that they are not meeting the goals EA set out for them. In its College Success Portfolio (CSP) Handbook, EA states, "At Envision Schools we are focused on rigor. By rigor we don't mean more content. We mean complexity: the ability to think like an historian or mathematician, the ability to know and use the leadership skills necessary in college and life, and the ability to reflect about one's personal journey as a learner. In short, we are about students *knowing, doing* and *reflecting*. Envision Schools graduates are ready for success in college and future careers because they know, do and reflect." Elsewhere, EA claims to offer students "a rigorous academic experience and a diverse, compassionate community in which to grow. Our students are inspired and empowered to be leaders in their high school education and their communities."

Something essential is clearly missing. In order for EA students to grow into scholars whose complexity arrives at the level of a successful college and

professional learner, they must identify and close the gaps in their academic readiness through educational opportunities that empower them to learn independently, as independent learning will feature in their college and professional experience. This requires teaching that ultimately facilitates students' active involvement in their own learning, enabling them with the capacities of "knowing, doing and reflecting", making the desired outcome mastery of both the content and the learning process.

I teach AP Psychology to juniors and seniors, a class and age ripe for transformation in all three knowing, doing, and reflecting capacities. Currently, my students do have the motivation and mindset of independent learners; for example, they are constantly initiating questions throughout a class and make connections to their lives when prompted. However, when my students are presented with opportunities to independently explore subject matter more thoroughly, they produce work of varying depth and quality. This has been evident in online posts to discussion forums, where in one assignment, students responded to a task requesting 250 words using between 120 and 463 words, with a median of 201 words. While all responded as required with some insight into how this material related to their lives, the discussions varied widely in the clarity and directness of their reference to our course material. Another gap manifests in students' ability to recognize contexts for applying what they have learned about writing: they often request detailed rubrics in order to understand basic expectations for written assignments, a support unlikely to be provided in higher education. It has also been present in the level of questions and answers students have created for readings, as

in when students responding to a reading assignment requiring that they create three questions and corresponding answers produced between half a page and a page and a half. Quantity alone is not a sufficient indicator of independent learning mastery; the degree to which students' written work shows applications of course objectives to their lives has also been lacking for many students across the class.

There is one central, recurring impediment to students' ability to apply course objectives to their lives: in learning new concepts and associated thinking processes, many students focus on superficially similar features of analogous examples, as opposed to the structural features those examples instantiate. They are distracted by the so-called "cover story", and as a result, they fail to notice and construct the components of the mental models to represent these new concepts. Several studies have demonstrated this to be a common impairment (e.g. Gentner & Toupin, 1986; Holyoak & Koh, 1987; Richland, Morrison, & Holyoak, 2006).

Equipped with incomplete mental models, students are unable to recognize and identify the constituent parts of unfamiliar examples, which precludes their solving analogous problems successfully. Essentially, this means many students are unable to transfer their learning from examples provided by textbooks or teachers, to other parts of their lives—both in and out of school—where it could help them. This means that students are not reaching the CSP Handbook's stated "ability to think like an historian or mathematician, the ability to know and use the leadership skills necessary in college and life."

The causes of this problem, as well as its potential solution, lie both in student thought processes and in the teaching activities intended to enable learning transfer. I have observed that my students often reflected greater confidence in their understanding than was appropriate to the level of understanding, suggesting inaccurate judgments of their own learning; and as a teacher, although I have focused on activities that communicate new mental models and give practice opportunities, I have not sufficiently emphasized opportunities for students to then construct the mental models for themselves. A great deal of research supports the need for this, as exemplified in the following: "New instruction of either declarative or procedural knowledge cannot always be either instantiated or directly encoded; often it requires the *integration* of new information with existing knowledge. This integration process can be facilitated by asking students to actively construct what they are learning" (Chi et al., 1994).

In assessing my teaching, it is clear that I give my students opportunities to actively *practice* what I want them to learn, but few opportunities to actively *construct* the new knowledge and integrate it into existing or new mental models. This is problematic for two reasons. First, well-developed mental models are one of the core characteristics of competence in a discipline ("think like a historian") and are required for enduring learning, so it follows that their absence would mean students will not achieve this. Second, without engaging in actively constructing mental models, students miss an important opportunity not only to learn the content, but also to learn *how* they can learn new content on their own, and thus become more independent learners.

In order to address this, my research has focused on teaching practices that encourage greater transfer of learning in ways that also teach students how to learn effectively on their own. These desired results have oriented my investigation around the development of metacognition and self-regulated learning as applied to analogical problem solving, with a particular focus on the combination of two learning strategies: self-explanation and similarity identification.

Literature Review

Introduction

Central to EA's mission is graduating students who can think like experts in their field (e.g. "like a mathematician"), able to work and learn independently as they know, do, and reflect. However, evidence in my classroom shows that students are regularly falling short of developing these capacities, many of which are encompassed by the terms "metacognition" and "self-regulated learning (SRL)", concepts which I will explore below in depth. I have concluded that as a teacher, I am not providing sufficient explicit support to help students develop these capacities. This problem and its repercussions are widespread; other researchers have similar findings, both in teachers' instruction and in students' learning and knowledge:

> In terms of instruction, there is a need to teach for metacognitive knowledge explicitly. Teachers may do this in some lessons, but in many cases the instruction is more implicit. Simply stated, many teachers assume that some students will be able to acquire metacognitive knowledge on their own, while others lack the ability to do so. Of course, some students do acquire metacognitive knowledge through experience and with age, but many more students fail to do so. In our work with college students (see Hofer, Yu, & Pintrich, 1998; Pintrich, McKeachie, & Lin, 1987), we are continually surprised at the number of students who come to college having very little metacognitive knowledge; knowledge about different strategies, different cognitive tasks, and, particularly, accurate knowledge about themselves. (Pintrich, 2002)

In several studies observing college students attempting to self-direct in a complex learning task, Azevedo and colleagues discovered further evidence that, "learners tend not to plan or activate their prior knowledge, rarely use metacognitive monitoring processes, use ineffective strategies, and exhibit

difficulties in handling task difficulties and demands" (Azevedo, Cromley, & Seibert, 2004; Azevedo, Guthrie, & Seibert, 2004).

Metacognition and SRL are lacking. My research investigates this in the context of learning analogical problem solving, one of the defining skills of an expert, and essential for independent learning (Nokes-Malach et al., 2013). Below, I will describe the nature of cognition in relation to problem solving; examine evidence from my classroom in that light; review the development of metacognition and SRL; and explain two specific strategies that emerge from this exploration as possibilities for an intervention that will improve my students' mastery of our objectives and expand their capacity as independent learners.

Cognition and Analogical Problem Solving

Neuman and Schwartz give an overview of how problem solving works, beginning with the structure of a problem itself. Problems can be understood hierarchically, moving from cover story—that is, the surface structure whose features are most readily apparent, what the story is "about"—to abstract description of the problem, the so called "deep structure" (Reeves & Weisberg, 1994). (In this paper, I will refer to "cover story" and "superficial features" to describe the former and "structural characteristics" or similar terms to describe the latter.) In order to solve a novel or "target" problem analogous to a "source" problem already learned, learners must be able to recognize the problem's deep structure and thus its solution, a process called "analogical transfer" (Holyoak 1984a, 1984b). How does this happen?

Analogical transfer requires the learner to have developed a schema representing the problem, a mental model of its deep structure. When learners see the similarities of a problem to one they have encountered and solved previously, it is clear what the problem is and requires (Bassok & Holyoak, 1989; Silver, 1981 (find the originals here)). The challenge this poses to teachers and learners, then, is how best to develop the schema that will enable subsequent analogical transfer.

Gick & Holyoak share that some of it may be done implicitly: "In complex domains much of the detailed knowledge shared by experts, particularly procedural knowledge, is likely to be implicit and not easily verbalized. A teacher may therefore have difficulty explicitly teaching such knowledge. However, by presenting the student with selected examples, the knowledge may be conveyed implicitly" (Gick & Holyoak, 1983). Further research, however, including that of Gick & Holyoak, demonstrates that strategies such as comparing analogous source problems facilitate schema abstraction more effectively than "automatic" or implicit learning through presentation (Gick & Holyoak, 1983; Reeves & Weisberg, 1994).

Even so, other studies reveal a problem that arises through this comparison strategy: the ability to identify the structural similarities is impaired by the presence of superficial features that compete for the learner's attention (e.g. Gantner & Toupin, 1986; Holyoak & Koh, 1987; Richland, Morrison, & Holyoak, 2006; Ross, 1987, 1989). There is a tension here: Gick & Holyoak (1983), among others, argue that comparing (analogous) source problems can facilitate schema abstraction; other studies say doing so impairs schema abstraction and "relational

correspondence" due to the distracting presence of similar superficial features. This invites the questions: **Are there strategies that can facilitate schema abstraction while also overcoming or eliminating superficial feature interference? And if so, can those strategies be taught and learned effectively?**

Metacognition and Self-Regulated Learning

The fields of metacognition and self-regulated learning (SRL) offer some promise in addressing this challenge through their focus on learners monitoring their own thinking and changing strategies accordingly. Further still, in order for students to become capable independent learners, they must develop these capacities for broad application beyond the problem described and the intervention proposed below. Indeed, Locke and Latham, two experts on goal setting and achievement, say, "Metacognition is particularly necessary in environments in which there is minimal structure or guidance," a description fitting most colleges and many workplaces, environments in which students will need to marshal a host of effective learning strategies to succeed (Locke & Latham, 2006; Zimmerman, 2002). I wondered, Can well-developed metacognitive faculties help students self-regulate such that they ignore superficial features which compete for their attention, instead honing in on deep structures and building mental models of those deep structures?

Defining metacognition and SRL will help in answering this question, though no widely agreed upon definitions for either of these constructs exist. I define metacognition as the awareness of thinking and its adaptation to the task. This includes awareness and adaptation in the moment as well as awareness of how

thinking works in general and its long-term adaptation to be better equipped for a wider array of tasks. Others identify this as including both knowledge and skill components (Veenman et al., 2006). Zimmerman breaks SRL into three phases: forethought, performance or volitional control, and self-reflection; they each include a strategy-related element: strategy selection, strategy implementation and monitoring, and strategy evaluation and attribution (Zimmerman, 1998). SRL clearly shares with metacognition a focus on the process through which "individuals attempt to monitor thoughts and actions, and to act accordingly to gain some control over them. It is, in effect, a marriage between self-awareness and intention to act that aligns these bodies of work" (Dinsmore et al., 2008). While noting that researchers have both conflated and distinguished the two terms, I will use them interchangeably, save for one point that Dinsmore and colleagues make: "For many self-regulation researchers, it is the environment that stimulates individuals' awareness and their regulatory responses. In contrast, those researching metacognition look to the mind of the individual as the initiator or trigger for subsequent judgments or evaluations" (Dinsmore et al., 2008).

Relevant to the discussion above, researchers have found metacognition to be instrumental in the acquisition of new skills, and, elsewhere, that metacognitive knowledge of strategies is related to transfer of learning (Carr and Jessup, 1995, as cited in Desoete, 2008; Pintrich, 2002). Still further, college students who employed SRL processes showed greater learning gains on a complex science topic compared to those students who did not engage in SRL processes. Notable in the contrast between the successful and unsuccessful groups was the presence among the

successful group, and the absence among the unsuccessful group, of monitoring their own understanding (Azevedo & Cromley, 2004).

Fortunately, a variety of studies demonstrate that metacognition and SRL can be taught explicitly and successfully. Kistner et al. (2010) found greater efficacy of explicit over implicit teaching in the context of "challenging tasks"; and Pintrich's remonstration of implicit metacognitive instruction, quoted above, discusses what happens in the absence of such explicit teaching (Kistner et al., 2010; Pintrich, 2002).

Consistent with the belief that knowledge must be actively constructed, Zohar & Ben David add, "This belief extends not only to the learning of concepts and strategies (Zohar 2004) but also to the learning of meta-strategies" (Zohar & Ben David, 2008). Rothstein and Santana offer a principle that might explain this: "If students are unaware of why and how they can use the skill they are learning, it is not likely they will transfer their newly acquired skills to a different task" (Rothstein & Santana, 2011). It would be more difficult for students to be aware of why and how they could use a new metacognitive skill if that skill were not taught explicitly.

Thus, these studies appear to support the idea that metacognition, if taught explicitly and through active construction, holds promise for learners in developing the awareness and strategies that facilitate schema abstraction through analogical comparison without the attentional interference of superficial features.

The question remains, however: What are these strategies?

Similarity Identification

There are two strategies whose combination suggests powerful increases in schema building, the consequent analogical transfer, and the long-term ability to succeed as an independent learner. The first is similarity identification (SI), and the second is self-explaining (SE).

SI is mentioned above in Gick & Holyoak's work. It involves comparing analogous examples of a given concept and articulating the similarities between them. Identifying these similarities creates the opportunity for students to actively construct a schema, which Gick & Holyoak posit as the mediating process in analogical transfer. Their results are compelling: among those who developed "good" schemas (subsequently evaluated by the experimenter), 91% solved a target problem effectively. For those whose schemas were assessed as "intermediate" and "poor", the figures were 40% and 30%, respectively. This correlation supports the idea that the more complete the schema, the more probable the analogical transfer. The researchers' subsequent experiments suggest a causal relationship here; if it is indeed causal, then it follows logically that interventions improving schema quality would improve analogical transfer.

Gick & Holyoak note, "Any device that highlights the causally relevant correspondences will facilitate abstraction of a more optimal schema" (Gick & Holyoak, 1983). SI is one such device, as noted, but it presents the following challenge: only 21% of the participants in the experiment above produced good schemas, and only 20% produced intermediate schemas (Gick & Holyoak, 1983). That is, a majority of people neither produced good nor intermediate schemas, and,

most likely as a consequence, a majority of people were unable to solve the target problem unprompted. What interventions, then, could improve the percentage of people able to abstract good schemas?

Self-Explaining

One promising strategy that could have this effect is self-explanation (SE), a process of explaining to oneself what one is reading, hearing, seeing, or thinking, which Chi and colleagues call "a constructive inferencing activity" (Chi et al., 1994). There is abundant evidence supporting the benefits of SE.

On its own, SE has been shown to improve the acquisition of problem-solving skills (Chi et al., 1994). In one experiment, students who provided more self-explanations (average of 15.3 per example) in studying examples solved problems more successfully (as measured by a post-test) than those who generated few explanations per example problem (average of 2.8 explanations per example) (Chi et al., 1989).

In addition to the numerous studies directly supporting the self-explanation effect, there have been several indirect findings supporting the same. In reviewing nineteen published studies on learning math and computer science in small groups, Webb (1989) found a positive correlation between achievement and learners *giving* elaborate explanations, finding few such relationships with students *receiving* elaborate explanations (Chi et al., 1994). This has deep implications for teachers of complex subjects—including this author; in my own practice, I know I am prone to giving such explanations and then creating opportunities for students to practice

doing what I have explained, skipping the important step of giving students the opportunity to elaborately explain themselves.

What is the relationship of all this to analogical learning and problem solving? SE serves to support the representation of problem, and thus solution, schemes in analogical problem-solving. Solving a novel problem can be described as "applying an abstract solution scheme previously learned" (Neuman and Schwarz, 1998). One study demonstrated that for questions requiring inferences of what was presented implicitly in a text, students who were "high explainers" answered correctly significantly more such questions than did "low explainers", suggesting they induced the knowledge necessary to do so (Chi et al., 1994).

Chi and her colleagues offer three processing characteristics of SE that might mediate learning: first, SE is a constructive activity; second, SE "encourages integration of newly learned materials with existing knowledge"; and third, SE is carried out in a continuous, piecemeal manner, thereby allowing for ongoing, minute revisions of the learner's mental model through the multiple opportunities afforded by the continuous process to see conflicts between one's mental model and the text's description of the model (Chi et al., 1994).

Conclusion

I believe this constructive, piecemeal integration pairs well with the SI process described above. SI provides a concrete, practical way for students to induce a schema; SE can support students in that schema induction while making their thinking more visible to them in the process. While studies comparing the two

methods exist (e.g. Neuman & Schwartz, 1998), I have been unable to find research investigating the effect of their combination. The well-documented benefits of each suggest at least an additive effect; in light of the discussion of metacognition, I believe that the effect may be synergistic due to the monitoring and strategy regulation that SE can encourage. In the terms described above, SI is a SRL mechanism, triggered by the external presence of two analogous examples, whereas the next strategy, self-explaining, falls squarely within the internally driven metacognitive domain. It is the combination of SI and SE that I will use in an effort to address the incomplete mental models and lack of metacognitive and SRL capacity observed in my students. This is summarized in the Theory of Action table below.

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Theory of Action						
Problem of Practice	Literature Review	Literature Review	Intervention	Literature Review	Expected Outcome	Research Methods/ Data Collection
What is the context? What is the problem in that context?	What do you know about the problem?	What has been tried in the past to address the problem? What was successful and why?	What are you going to try? Why do you think it will impact the problem? What is your rationale?	What do we know about quality interventions of this kind?	What do you think will change/ improve?	How will you know if it changed/ improved? What data will you collect?
In learning new concepts, students are distracted by the superficial features of examples. This inhibits their noticing of the features of the deep structure underpinning the example, and thus impedes the development of a mental model that represents	Students' lack of metacognition contributes to this in that they lack awareness of their own distractedness, lack inhibitory skill, are unaware of their own thought processes, and as a result, fail to regulate their thinking and engage appropriate	Teaching metacognition has been helpful in developing students' capacity to monitor their own thinking and adjust it appropriately. Specifically, teaching self-explaining has improved the construction of problem-solving skills	Teach students how to self-explain and the benefits thereof. Then, give students two analogous examples of a new thinking process and ask them to self-explain as they write the similarities between the two examples. Finally, assess performance on	Metacognition in its many referents can be taught successfully to improve student learning. Specifically, self-explanations are effective in improving problem-solving skill development (Chi et al., 1989). Interventions	I think students will understand new thinking processes and develop schemas more completely with less interference from non-structure-related content. I think this will enable them to transfer this skill and	I will record students thinking aloud during task completion, then teach them self-explaining, then record them in task completion again, coding for the presence of self-explaining. I will then present a new topic and instruct them to identify the

that deep structure. Consequently, their analogical transfer is impaired.	strategies.	most likely because it requires the active construction of the problem. Also, identifying similarities between analogous source examples has been helpful in facilitating analogical transfer because it induces a schema, helping to overcome fixation on content similarities while highlighting structural ones (especially when the examples' content is	a target problem, immediately and one week later. I think the self-explaining process will bring students' attention to the their thought processes, and in having to make sense to themselves of why a thought process is happening in the way it is, students will highlight some of the structural elements. This will make it easier to identify structural as opposed to content	requiring subjects to identify similarities have been shown to induce schemas effectively and facilitate analogical transfer (Gick & Holyoak, 1983). In a separate, non-similarity identifying task, self-explanations were helpful in facilitating analogical transfer (Neuman & Schwartz, 1998).	understanding to analogous situations post-intervention. I also think that they will develop two methods of learning—self-explanations and similarity identification—that enable them to be more capable independent learners.	similarities between two analogous examples. Directly afterwards and one week afterwards, I will test their performance on a target analogous problem. Finally, in the teaching of the metacognition, I will code the similarities students identify between successful SI examples.

		unrelated). Finally, self-explanations of one analytical reasoning problem have been shown to increase analogical transfer, most likely because it facilitates better schema mapping.	similarities, creating better developed induced schemas. These well-developed schemas in turn will facilitate higher rates of more complete analogical transfer. Finally, I will teach the strategy, evidence, and logic of the two metacognitive pieces. Metacognition must be actively constructed, just as content must be (Zohar & Ben David, 2008).			

Intervention & Data Collection Plan

I plan to incorporate both strategies in teaching a new concept to my students. First, I will give students an SI task on an initial topic (Grudges and Forgiveness) and have them record themselves thinking aloud while completing the task in order to establish a baseline of how much self-explaining is already happening. I will then model and teach SE, making time for students to listen to their own recordings and self-assess for SE presence. Next, students will have another opportunity to practice SE while doing SI. This initial topic serves principally as a way for students to learn and practice SE and SI in preparation for using it in learning the second topic, Nonviolent Communication. Each of the student products and recordings mentioned, as well as those described below, will be transcribed and coded for the type of SE and presence of structural feature identification. This allows for "on-line" measurements of students' metacognition and strategy usage, which can be correlated with learning outcomes (Veenman, 2005).

Gick & Holyoak's research (1983) "predicts that any manipulation that can facilitate schema formation will boost analogical transfer," and they conduct experiments that successfully show how offering a general principle or a diagram increase the number of "good" schemas produced and the analogical transfer that results (Gick & Holyoak, 1983). Drawing from this, I will introduce the next topic with some background reading and teaching, similar to the general principle mentioned above. Then, I will present my students with analogous examples of the new topic and instruct the students to do both SI and SE, recording themselves as they do so. I will then give them a target problem to solve based on what they have

learned, followed by a delayed target problem of the same nature one week later to evaluate what learning will have endured.

Because my ultimate goal is helping students become more independent learners, I will make explicit for students the structures of our learning and the reasoning and evidence behind them. In line with Zohar & Ben David above (2008), my intervention will also create opportunities for students to actively construct the metacognitive knowledge and skills themselves. In the week following the delayed target problem, I will ask students to identify similarities of two complete schema produced by students who also successfully solved the target problem.

Overview of Intervention

	Component (What am I going to do?)	**Activities (What happens in that—what do we all do?)**	**Purpose/Question to be answered**	**Data to be Collected**
1.	Keep a researcher's journal	N/A	How are my thoughts about metacognition evolving? How is this influencing my teaching practice?	Journal entries—definitions, associations, effect in lesson planning, awareness of usage
2.	Record students thinking aloud pre- self-explaining intervention and show it to them	Students are given a SI task for analogous problems (grudge story -> forgiveness story: Dana, Marilyn, and John) Students record themselves thinking aloud while completing task	Are students using self-explanation strategies? Does self-explaining improve their task goal achievement?	Transcriptions of student recording, coded for presence of self-explanation Scoring of task achievement Student self-assessment and teacher coding assessment of their recording Researcher's Reflective Journal
3.	Teach students to self-explain while working on a problem	Survey students if self-explain Teacher models own self-explanation process, students take notes (Susie) Students listen to their own recordings and self-assess	Teach students self-explanation strategies as a metacognitive skill and as a way of obtaining data—for student and researcher—to assess existing metacognitive use and as an independent variable in schema induction	Survey data Student Work Samples Researcher's Reflective Journal (observations, reflections on what worked in teaching this and what didn't)

		Teacher gives feedback	(Since better self-explanations are linked to better understanding and better Analogical Reasoning)	
4.	Record students self-explaining, post intervention and show it to them	Students are given an SI task (Jill & Jim) Students record themselves self-explaining while completing the task Students watch/listen to the recording, then complete a similar task (Shelley & Mr. Nehoc), self-explaining again.	Are students using self-explanation strategies? Does self-explaining improve their task goal achievement? Does listening to how they themselves worked through a problem change how they do so?	Transcriptions of student recordings, coded for presence of self-explanation The SI task itself Student self-assessment and teacher assessment of their recording Interview/survey students pre and post to CFU Researcher's Reflective Journal
5.	Provide analogous examples of new thinking process with some explanation. Give instructions to identify similarities between them.	Students will write similarities of two structurally analogous examples demonstrating the new thinking process (student to teacher, and mother to child) Students record themselves self-explaining while completing the task	Objective is for students to abstract the process/schema from concrete examples: Can students use the self-explanation strategies they have learned to articulate the thought process they are using, thereby inducing a novel schema?	Written copies of students' comparisons, to be coded for presence of structural (schematic) components Transcriptions of students' recordings

6.	Provide target for analogical transfer (immediately after)	Students will be presented with a series of examples, one or some of which require the application of the thinking process (nonviolent communication framework of understanding: older sister to younger sister) they just learned Students record themselves self-explaining while completing the task	Is the novel schema retained and ingrained enough to facilitate analogical transfer? Are the metacognitive skills present and helpful in this transfer?	Students' answers, to be scored for presence of schema-relevant components. Then see if there is a correlation between presence of SE & schema complexity, and presence of SE & target performance. Compare this to first NVC conversion attempt. Transcriptions of students' recordings
7.	Provide target for analogical transfer (delayed test)	Same as above, one week afterwards (boss to employee)	Same as above	Same as above
8.	Teacher observation & student survey	Teacher observes and surveys students	After the intervention, are students initiating use of either of these strategies in the learning in class or at home?	Teacher's written observations in researcher's journal; students' written survey responses
9.	Teaching metacognition through active construction	Students identify similarities of two analogous examples of students who created complete schemas and successfully solved the target problems.	Metacognition must be actively constructed as well.	Students' identification of similarities.

Research Methods

Driving my entire research was the desire to help students become more capable independent learners. With that in mind, I wanted to answer these specifi questions: Can the strategies of Similarity Identification and Self-Explanation facilitate my students' development of more complete mental models? And if so, does this result in more complete and enduring analogical transfer? Finally, does t combination of the strategies yield any additive effect than using just one of them?

I carried out the intervention while teaching on two topics during our Emotions, Stress, & Coping unit. The first focused on converting a "grudge story" into a "forgiveness story", drawing on the work of Stanford psychologist Fred Lusk in his book, *Forgive for Good*. The second involved learning the Nonviolent Communication ("NVC") process of communicating developed by Marshall Rosenberg in his book, *Nonviolent Communication: A Language of Life*. I chose to d the intervention across two topics instead of one in order to use the first one to teach the logic and process of SI and SE, and then assess students' use of it as they learned the second topic.

In practice, the intervention varied somewhat from the plan outlined in the table above. After introducing the first topic through direct instruction, I gave students two examples of a grudge story and asked them to identify the similaritie while recording themselves thinking aloud. This was intended to serve as a baselir to assess both the presence of self-explanation features in their thinking and the types of similarities they identified initially. I then asked students to convert a grudge story to a forgiveness story while thinking aloud, developing a baseline for this particular competency.

After these initial tasks, I modeled the self-explanation process, narrating and showing my thinking on a handout as I identified the components of the deep structure of a grudge story and considered how to convert it into a forgiveness story. The handout contained a transcription of just this. At this point, I intended to have students listen to their own recordings and self-assess for the presence of quality SE while I gave feedback, but I chose to prioritize the learning in the curriculum and skipped to the next step of the intervention.

In the next step, students were given another opportunity to identify similarities between two grudge stories and between two forgiveness stories that had been converted from these two grudge stories. In the final part of this topic and learning phase, students did SI on another pair of grudge stories and then converted one of them to a forgiveness story.

The second topic and phase involved a similar but shorter structure. Students identified the similarities of two "violent communication" (VC) statements and attempted to convert them to nonviolent communication (NVC). Then they identified the similarities of the model conversions to NVC I had created. The target followed this, in which they attempted to convert a VC statement to NVC statement. A "delayed target", a task of the same nature, followed one week later to assess enduring understanding.

Data analysis focused on scoring the students' SI work for the presence of the deep structural components and scoring their solutions on target tasks (conversions to forgiveness stories or to NVC) for the presence of each of its components. I began by identifying the elements of each process that I wanted students to master and

assigning them each a code. This led to a quantitative representation of presence and absence of both the structural and the superficial components in each SI.

After transcribing students' recordings of their SE, I completed a similar process for generating SE codes. I began by drawing on the work of previous researchers in this domain, starting with four codes, three of which were demonstrated to have positive correlations with problem solving and one of which held an inverse correlation (Nokes-Malach et al., 2013). Each structural component in the SI had a corresponding SE code as well. As I listened to the recordings and moved through the transcriptions, I discovered that students, in their ongoing and successful careers of challenging my well-crafted plans and refining my own understanding and teaching in the process, regularly made structural descriptions that did not neatly match the elements I had identified and targeted; thus, the process was iterative, alternating between coding the transcripts for the presence of the key structural elements and creating codes for those elements. This too led to tallies of the presence and absence of substantive and superficial SE in each transcription.

There were four codes that, drawing in part on the research of Nokes-Malach and colleagues referenced above, I hypothesized would be inversely correlated to successful analogical transfer: S-E Reformulation, restating the information in the text without adding anything; S-E Superficial Features, engaging with the cover story in a way that does not generate any deeper understanding of it; S-E Unrelated Think Alouds, in which students may go off on a tangent and discuss something unrelated to the text (e.g. "though he's justifying what he's saying. I think I say

justified a lot. I think I like that word."); and S-E Expression of Doubt, where students express uncertainty about the correctness of their thoughts or work (distinct from S-E Questioning, in which students pose a question to themselves). Because the recordings were relatively short and the overall number of SE per task consequently low, I assessed the total effect of these four types of SE instead of doing so individually.

Once I had coded all the data, I created a table for each topic. Each section had a column for scoring the task, either similarity identification or conversion in the target, followed by two columns, one for the number of helpful SE comments and one for the number of unhelpful ones. I then counted the number in each task and transcript, filling in the tables. At this point, I calculated correlations between the various columns.

In addition to the extensive coding and analysis in this quantitative analysis, I studied the content of students' transcriptions and made observations along the way, adding them to observations in my research journal, and investigating connections to student learning. Finally, I recorded students' comments throughout the teaching and intervention.

Analysis & Findings

The quantitative analysis below focuses on students' explanations and performance in the second part of the study and after they were trained in SE. The qualitative analysis and discussion address both parts of the study. A few central findings emerged: structural SI supports enduring analogical transfer, while

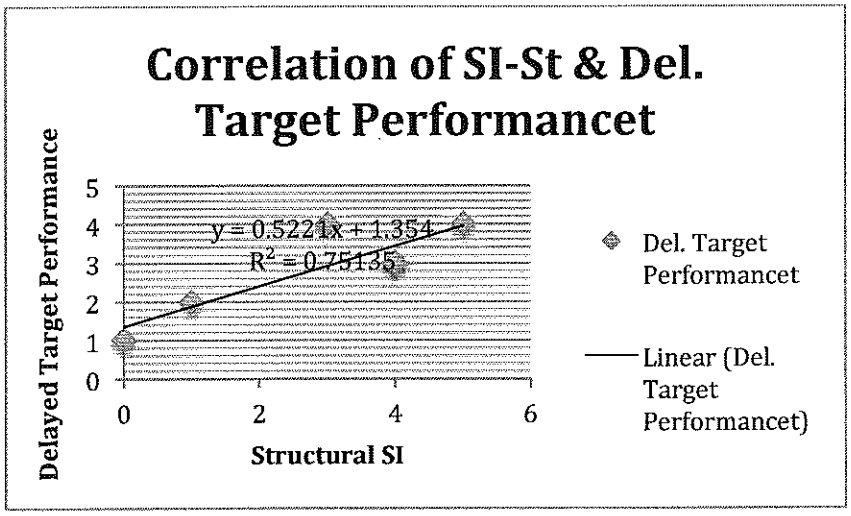
superficial SE detracts from both of these; substantive SE without superficial SE appears to support both structural SI and enduring analogical transfer; gaps remain in students' metacognitive capacity, but signs of learning were also present.

Analysis

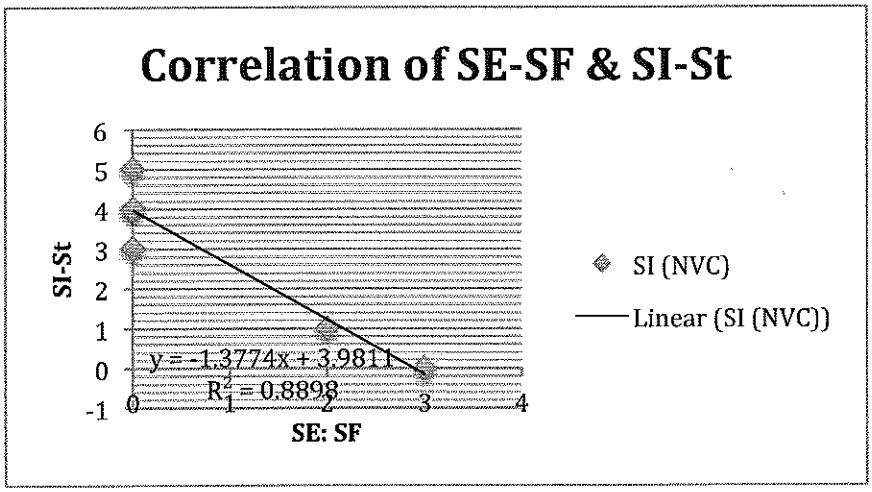
Several correlations appear in the data. Graphs of statistically significant correlations ($p \leq .05$) are shown below. Analysis reveals:

1. A positive correlation between substantive, on-topic SE and accurate SI (r= 0.7575, p= 0.0811);
2. A positive correlation between substantive, on-topic SE and performance on the target (r= 0.7278, p= 0.1011) & delayed target (r= 0.6577, p= 0.1557);
3. A positive correlation between structural SI and performance on the target (r= 0.8006, p= .0557) & delayed target (r= 0.8668, p=.0254);

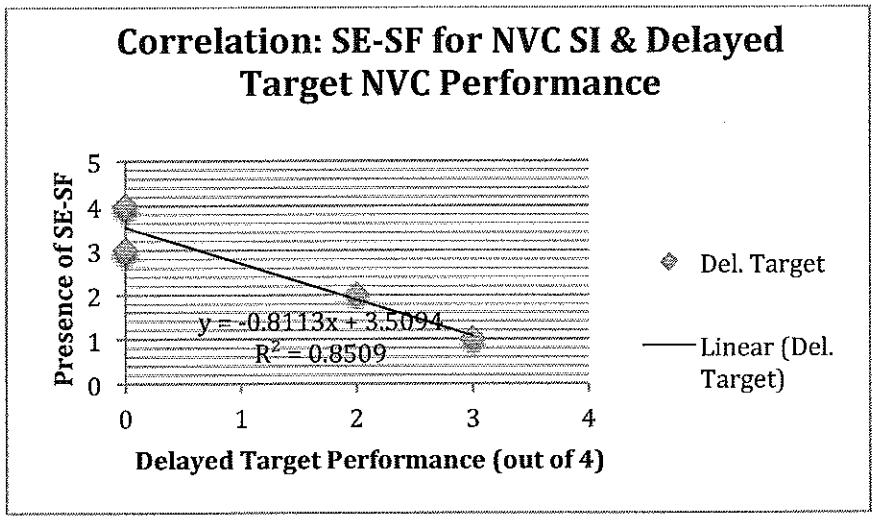
Note that there are six data points, but fewer appear in this and other graphs when two or more points share the same coordinates.



4. An inverse correlation (r= -0.9433, p= .0047) between superficial SE & structural SI;

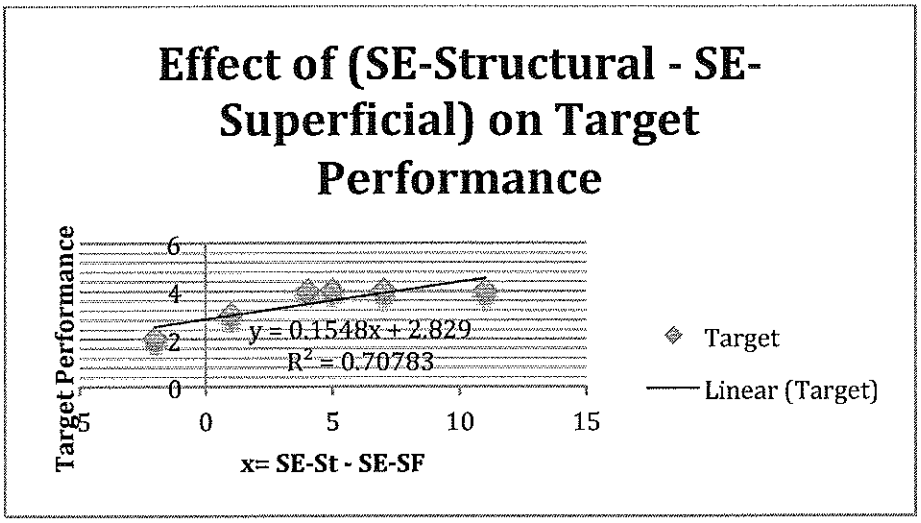


5. Inverse correlations between superficial SE during the NVC SI task and performance on the target (r= -0.8093, p= .0511) and delayed target (r= -0.9303, p= .0054).

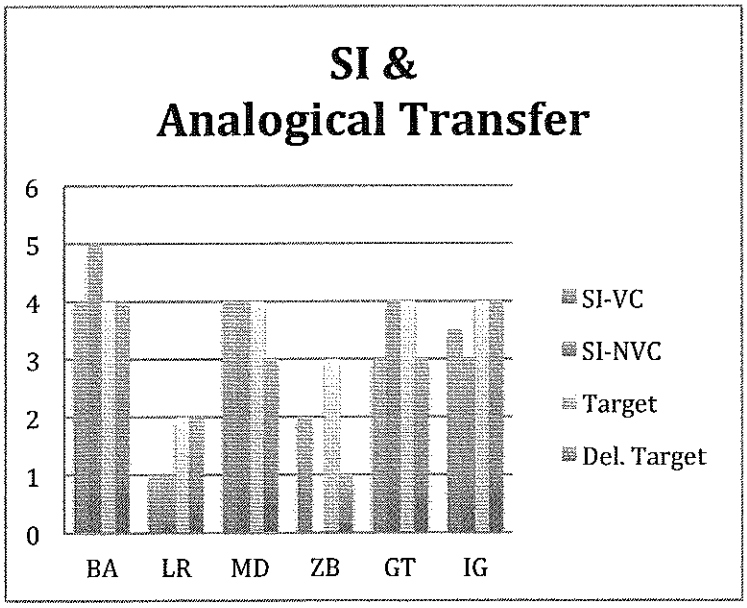


6. Finally, there was a strong correlation (r= .8413 , p= .0358) between a composite SE measure and performance on the target. The composite

measure was the number of structural SE a student gave less the number of superficial SE the student gave on the NVC SI task. This composite measure is intended to approximate the distracting effect that each mention of a superficial aspect might provide.



Discussion



The data support a fundamental claim discussed in the Literature Review that the completeness of a student's mental model, as measured by the structural

similarities they identified, predicts analogical transfer (i.e. Gick & Holyoak, 1983; Neuman & Schwartz, 1998). As the "SI & Analogical Transfer" graph represents, students who developed more complete mental models had more complete and more enduring analogical transfer on both immediate and delayed target problems. For example, one student, BA, identified the following similarities between NVC examples: "state what the action was; the feeling; explanations; offer a alternative; peaceful tone." A week later, her delayed target response included each of these: "When I needed that report yesterday and I didn't get it, I felt frustrated because I need to look responsible in front of the CEO. Next time can you get me the papers needed on time to avoid complications?" This is a stark contrast to LR's SI work: "Both give a second chance; end with the question," and her delayed target, "When I asked you to have the report ready yesterday and it wasn't ready it made me feel frustrated because how I look as a irresponsible peron [sic] in front of the CEO."

In quantitative terms, the statistical analysis supports the same pattern, showing stronger correlations of greater statistical significance between structural SI and performance on the *delayed* target, as compared to the immediate target. The same is true of the inverse correlation between superficial SE and *delayed* target, as compared to the immediate target. This offers further support that those strategies highlighting the deep structure of a new process facilitate analogical transfer that is both more enduring and more complete; notably, this second correlation also suggests that cognition unrelated to structure impedes learning.

While the design of the experiment does not permit a conclusive response to the question of whether SE increased structural SI, some observations and

correlations do inform the conversation and offer moderate, if inconclusive, support for that hypothesis. Superficial self-explanations are inversely correlated with structural SI, a significant finding that previous researchers in this area have not explored or noted. This correlation supports the idea that students fail to recognize structural similarities because they are thinking about and explaining the cover story, not features of the underlying structure. While the study does not reveal the extent or direction of changes in superficial suggestions, it does suggest the potential for a causal relationship in which learning to self-explain better, and thus decreasing superficial SE, would result in increased structural SI and schema induction. This idea is bolstered when taken in conjunction with the positive correlation discovered between target performance and the composite measure (substantive SE less superficial SE).

Another comparison offers some insight into whether such learning to self-explain better actually happened during the intervention. In comparing the percentage of the underlying structural similarities students identified between phase one and phase two, students were more successful at identifying the structural similarities in the phase two violent communication task (mean of 2.75) than the phase one grudge story task (mean of 1.75). Even so, they were equally successful, on average, in doing so for the nonviolent communication and the forgiveness story (mean of 2.5). As such, it is difficult to know if students' SE capacity increased. These mixed results must also be stated with caution; while there were four key structural features to be identified in each, the concepts are very different and may not be comparable in complexity and difficulty. In addition,

the teaching and reading that led up to each differed, presenting another confounding variable not considered in this analysis. Further commentary on the limitations of this intervention design and opportunities for future research is below.

One effect of thinking through and explaining an idea is that doing so may make it more memorable later. In comparing the SE of two sample students, the first student performed better on the forgiveness conversion than the second and had significantly fewer superficial SE than did the second. One hypothesis of the mediating factor that I would like to investigate further is that the second student's cognitive and verbal production of many unhelpful superficial ideas may not only distract her but also make those ideas more salient in her memory, perhaps decreasing the salience of the important ones when it is time to write them down.

This would explain the several instances in which students referenced one or more structural components in their SE but failed to include them in the written SI. For example, in the first phase, LR verbally identifies a key structural component, letting go: "so she knows she's not letting go. so she knows she's [...] it's HER fault" but "letting go" does not make it into the similarities she writes down. Another student, MD, explained the two examples with three of the four primary structural components (breaking their rules, taking it personally, and blaming), but only the second and third were written down as similarities: "So both Jim and Jill were complaining about someone else who was breaking their rules, I guess their inability to "like" or "love" or "feel affection towards" them...umm and so they took it personally. and so she, Jill claims she had a terrible life and Jim thought that Mr.

Ramirez just didn't like him. -no-like-no-like-not-a-good-life, and yea they blamed their teacher slash mothers. well she blamed her mother, he blamed the teacher." Clearly, what is ultimately reflected in the written work does not always include the all the necessary elements, some of which are included in a student's self-explanation. This extended beyond the SI task to performance on the target as well. For example, one student's written work did not include the "need" component in NVC, but her self-explanation showed that the boss "could have said that [the employee] ... could have used his time more responsibly. to have had umm done the work since it was important for the boss so that he wouldn't have gotten him in trouble with the CEO." This identifies the boss's underlying motivation and concern—his need—but that does not make it into the final answer. I had hoped that learning to self-explain would increase the structural focus and decrease the superficial focus; while it is not certain if this happened, it is certain that room for improvement remains.

This prompts a question: What is required for students to focus on core elements of a process, as opposed to other thoughts they have and find interesting? If students are mentioning the core elements in their explanations but not writing everything they think, in both written tasks and assessments, they are not demonstrating the full extent of their knowledge. This particular shortcoming is what I would call a filtering or discriminating deficiency in which students are not appropriately distinguishing between what is relevant to the task goal and what they find relevant to themselves. Once students are identifying structural features as

well, it could be fruitful to explore helpful ways of discriminating between the many thoughts they have had to identify the core ones.

Some students did not reach this point, still enraptured by the cover story. In the grudge section in phase one, LR seems obsessed with fault-finding, as evidenced by the contrast between her SE and another student's in response to the following example. "Shelley hates her mother because she was always working instead of paying attention to her. Further, she was overprotective... she thinks this is the reason that she hasn't entered college as confident as some of the other students." LR self-explains: *"umm no i don't think that just cuz your mom does you shouldn't be able to do good in college, that's YOUR responsibility, not your mother."* ZB, on the other hand, self-explains, *"so she blamed her mother for not for her not developing social skills."* The contrast demonstrates LR engaging with the cover story while ZB discerns the structural feature. This leaves me with the question: is SE actually helping LR revise her mental model?

In this case, it appears not and prompts an insight into when and how SE might be better applied: SE was done AFTER the independent reading and instruction portion—it may have been helpful to engage students in more SE during the independent reading process. The three processing characteristics that Chi and colleagues hypothesize as mediating the effects of SE—it is constructive; integrates with existing knowledge; and as a continuous, piecemeal process, can allow for ongoing revisions of a learner's mental model—suggest this would have been helpful to LR and others in noticing the conflicts between what she knew and what she was learning (Chi et al, 1994).

Including SE to highlight conflicting or different mental models might have been helpful in another respect as well. Because students had read the NVC background before doing the grudge and forgiveness story work, several used their knowledge of NVC in their understanding and explanation of this section. For example, one student (BA) wrote, "They're-both-mad-and-angry because-they-lack-what-they-need, what-they-demand," a clear application to a grudge story of the needs consciousness espoused in NVC. Students also used elements of the forgiveness story in the NVC section, as in when one student picked up on the blame features present in an example of violent communication, something emphasized in the "grudge story" structure we had previously discussed. I had not addressed in my teaching the overlaps and complementary aspects of each mental model, an oversight I believe contributed to students' application of each mental model to the other. For teachers teaching related concepts, this serves as an important reminder to explicitly distinguish between the processes used for each concept, as well as to teach and discuss how they complement and support each other. Complementing suggests that their combination can be more powerful than one by itself. It stands to reason that this could only be possible when one mental model neither totally blocks, nor is replaced by, the learning of another, and when the appropriate context for applying aspects of each is clear in the learner's mind. Researchers have demonstrated that schema induction through SI can facilitate the recognition of appropriate contexts for applying learning (Neuman & Schwartz, 1998).

Did the intervention support students in becoming more capable independent learners? While there was clearly room for improvement in this regard, as discussed above, some observations suggest the intervention did succeed in this manner. As mentioned in the Literature Review, "If students are unaware of why and how they can use the skill they are learning, it is not likely they will transfer their newly acquired skills to a different task" (Rothstein & Santana, 2011). In teaching SI and SE, students demonstrated an understanding of its utility. Upon hearing the explanation of the logic and evidence behind the strategies, one student, unsolicited, exclaimed, "We should, like, learn this before we learn math," and another quickly followed with, "or before we start school."

The SE of a different student, BA, revealed further insight into the benefit of teaching metacognition systematically and over time. By way of background, at the beginning of our course I teach students some fundamentals about memory and neural pathways, centering on two related ideas: "Neurons that fire together, wire together" and "Practice makes permanent" (Hebb, 1949). My purpose in doing so is in large part to help students understand how knowledge and skill are developed. When they have the experience of not knowing or understanding something, I encourage them to reframe that in terms of their brains' synaptic development, as in, "I haven't built the pathways yet." In the intervention, BA began to express some doubt during her SE, only to interrupt in just this way; she stated, "I dunno—I mean, I haven't built the pathways yet." A second student demonstrated her understanding of the same ideas, reflecting after one task in the first phase, "yea, I understand my thought process better when I'm getting mad." She continued, "I think I understand

the grudge one better because I have practiced it more." Such self-awareness, understanding of cognition, and judgment of learning are key aspects of metacognition and SRL. I interpret these students' statements as evidence that this systematic teaching was effective, which I believe is a direct result of explicit teaching throughout the year as well, as the many opportunities and class support to practice that. This is significantly more than the instruction and support for SI and SE in this intervention, in which we spent two class periods practicing these strategies and hoping they would be used effectively the next week.

Thus, three takeaways from the intervention stand out with regard to growth in independent learning capacity: analysis suggests an increase in some students' metacognition to some degree; it reveals the remaining gaps for some students; and it demonstrates that some metacognitive growth did take place over the course of the year, preceding the intervention but—not coincidentally—during the course of my research into the topic.

Conclusions, Implications & Limitations

My analysis and findings support those of the research surveyed above and show that much of it is generalizable to the context of my classroom: substantive, on-topic self-explanation appears to bolster the creation of mental models and facilitates higher performance on transfer problems. Likewise, similarity identification is a useful tool for inducing these mental models and has a similar correlation with analogical transfer performance. The correlation for each was higher and more statistically significant on the delayed transfer problem than the

immediate one, suggesting that these two strategies do have an enduring effect. Superficial self-explanation appears to detract from the creation of mental models, impeding learning as a consequence.

One pivotal implication for other teachers, as mentioned above, is that *giving* elaborate explanations, not *receiving* elaborate explanations, is highly correlated with achievement (Webb, 1989). Teachers are usually in the position of doing the former, finding themselves clear on the material, but can often make more opportunities for students to take that role. A point for further exploration is in students' failure to produce the right material at the right time, even when they have thought through and explained this to themselves.

One of the fundamental limitations of this study was in its ability to measure any added value derived from combining the SI and SE strategies in comparison to using only one of them. The model I used could be adapted for this, and future researchers might assess this focus in a setting whose numbers and nature were conducive to a design involving a control group and a treatment group. Even so, both the quantitative and the qualitative analyses suggest that each of these can be helpful to students who want to become more capable independent learners, and to teachers who want to develop such students.

As a teacher, the intervention process revealed a number of helpful reflections applicable in my own work and for others. The process of listening to students think and explain aloud gave me familiarity and insight into their individual patterns and styles. It provided such richness that I found myself wishing I had done something similar at the beginning of the year as I think that my

deepened sense of each student's processing patterns would allow me to adapt my teaching with greater nuance and purpose. Even without the process of transcribing, I think the practice of listening to the thought processes of individual students—live or recorded—for a couple minutes could inform how teachers respond to them. For example, the beginning of the intervention mirrors what typically happens in my and many classrooms: I instruct the students on a new topic; we move through an example together; they look at similar examples; they practice on their own; I give feedback; they practice more. All too often, however, I think the feedback is focused on the performance of a new process while neglecting the mental model underlying it; still less frequent a focus is the process of constructing that mental model. Listening to students explain can draw a teacher's attention to both of these areas and help the student identify patterns themselves that are helpful or that are distracting.

The research and its application brought into focus my own metacognition and increased its presence in my work, a focal I highly recommend to other teachers in light of its many benefits. In highlighting the strategies I was using to learn the material for my research, it helped me see where students might make errors without having fully developed those strategies. Above all, the intervention returned my attention repeatedly to mental models—knowing that they must be explicit, actively constructed, practiced, and differentiated from related mental models and superficial material. I noticed, for example, that I spent more time focusing on students' understanding the structure of a problem than I did on the structure of a solution, which related to but did not perfectly correspond with the problem

structure, a distinction from previous research on this topic (e.g. Gick & Holyoak, 1983). As mentioned above, I also discovered I had overlooked opportunities to teach and discuss how related concepts complement and support each other, facilitated through explicit teaching of their structures—a great strategy for myself and other teachers to leverage in building complexity. While increasingly I become aware of how essential these points are in helping students develop mastery of our subject matter, this intervention fell short in this light in a central focus: developing students' metacognitive capacity.

Before the intervention, I realized that my intervention plan did not include students' active construction of the schema for metacognition itself. While I have argued here that all knowledge needs to be actively constructed, and upon this realization had planned a way to do this using examples from the intervention itself, crafting and executing this would have taken longer than we had at the end of the school year, so I did not include this part of the plan. As mentioned before, and for similar reasons, I also excluded the planned student self-assessment step. Unfortunately, one of the students whose SI and SE were incomplete and focused on the cover story harbored the false impression that she was already using the SE strategy. LR claimed, upon my introduction of SE, "I do that all the time. [e.g.] this connects back to this point." This was compounded by a focus of feedback only on the immediate and delayed targets not on the SI and SE quality. Active construction also requires ongoing revision—supported by feedback on accuracy—and since these were lacking, it is probable that this student did not amend her judgment of her own competence in this domain. A takeaway for teachers is that when teaching

both strategies and content, both need active construction and feedback for all students to master. SE is one way for students to engage in the active construction piece, surfacing for themselves their existing mental models to enable ongoing, piecemeal revisions.

Several challenges arose as I carried out the intervention. First, final participant numbers were smaller than I anticipated, arising due to inconsistent attendance, technological difficulties, and the time of year at which the intervention occurred. This resulted in only four students' data being available for use from the first phase and six students' data from the second phase (the two additional students were trained in SE & SI in a subsequent class and individually with the teacher—variables not considered in the overall analysis). Additionally, there were parts of the data gathering that would have required sacrificing time spent on other parts of the curriculum. In the choice between gathering further data for my research and ensuring students learned the planned content, I generally chose the latter.

Along these lines, I had initially planned to survey my students to understand their use of the subject metacognitive strategies. Along with the time investment it would have taken, Bannert & Mengelkamp's exploration of various assessment methods dissuaded me from doing so, demonstrating that online methods were more reliably predict learning outcomes.

> "In his recent review, Veenman (2005) classified metacognitive skill assessment methods as off-line and on-line methods. Depending on the moment they are conducted, he distinguishes off-line methods, which are performed prospectively or retrospectively to learning, from on-line methods, which are conducted concurrently during learning. Prospective and retrospective assessments are usually obtained by questionnaires and interviews and often fail to predict learning outcome. Therefore, for assessing metacognitive skills in particular, he recommends

> on-line methods, which are more accurate and valid." (Bannert & Mengelkamp, 2007)

I decided to focus instead on the recordings students produced. The same authors share a precedent for this in a "study by Hill and Hannafin (1997) [that] employs think aloud protocols to qualitatively assess the use of learning and metacognitive strategies. Due to the huge effort of scoring verbal protocols, data of only four participants are reported in their study." (Bannert & Mengelkamp, 2007).

This focus on recordings revealed another interesting, unanticipated confounding variable, one that makes sense given the nature of the classroom. This was "contamination", by which I mean the effect of students overhearing other students explaining nearby. Consciously or unconsciously, this can influence a student's whole understanding. This appeared distinctly in one section, where after not having mentioned anything related, the speaker suddenly identifies and focuses on lack of "control" as a key similar feature between examples. In the background, another student can be heard saying "control" just before the speaker does so. I do not suggest that building on the ideas of other students is not adaptive—in fact, capable independent learners quickly seize on others' helpful ideas—but it does mean that some transcriptions do not represent a student's individual capacity for SI. This would have a consequent effect on the correlations derived from the data.

One notable challenge and potential limitation in creating reliable data through the coding process was making sense of the student work while minimizing my own bias. In a few cases, the transcript was helpful in trying to understand the

meaning of the students' short-hand, but using the transcript to make sense of the similarities identified, and then trying to find a correlation between them, introduces the possibility for higher correlation. In addition, the experimenter is not blind. While this would not be ideal in action research, it has certain effects: I noticed in my coding that my own perceptions of my students were coloring and influencing my coding. While I am not fully aware of their specific influence, I did notice thoughts such as, "Oh, [student], she didn't do as well on the test question, which makes sense that she would have [unhelpful code] in her explanation." On the whole, the overall effect of this could be to create a correlation that would not otherwise manifest (by virtue of a greater or lesser likelihood to identify a code upfront because of the lens through which I am viewing the student). This was especially true in cases in which students' answers approached the structures taught but did not perfectly adhere to them, introducing a degree of judgment—and thus the potential for bias—on the part of the researcher. In a study with more resources available, it would be ideal for a scorer with no relation or knowledge of the students to score and code their work, reducing the potential for preconceptions to color the coding process. Still more rigorous would be to have two people score and code the same work, comparing to see where they differ and reconciling appropriately.

In terms of my growth as a researcher, the intervention and action research process was immensely productive. I discovered several important truths and limiting beliefs: data collection in a classroom context is neither neat nor perfect.

This reality is troubling only in the face of the limited and limiting belief I harbored that I am trying to develop and define some universal truths, and thus that I need my collection to be uniform, precise, perfectly replicable, etc. I fooled myself into thinking—temporarily—that if I had all six recordings for the first phase as well instead of four, then I would really be able to make some solid, reliable claims. How preposterous! Not that I shouldn't make every effort to find robust conclusions through sound methods, but my sample size is so tiny that even finding correlations with confidence is a challenge—I could not possibly extrapolate with confidence from my class.

What does that mean for the purpose of my data and study? It is certainly significantly more data than what most teachers collect and use on a regular basis, compared to many teachers whom I have observed regularly making unchecked inferences about what is working and what is not working. My action research process is much more rigorous and informative than that, which is representative of action research versus laboratory research. The laboratory has the advantage of reducing variables in the data collection as well as in the intervention, but action research takes place where the action is. I can without hesitation make purely descriptive observations about the correlations within the sample: in these conditions, for these people, by this experimenter, this is what happened. Each of these many variables changes, and it is important to stay conscious of the contextual assumptions in which the data was produced so as to adapt as necessary when the context changes. In other terms, it is important to construct actively and explicitly the mental model derived from the research, so that it can be transferred to

situations that are analogous and adapted for ones that are not. Befitting research focused on metacognition and mental models, I conclude with this reflection of my increased awareness of what mental models are appropriate to guide teaching and research in the classroom.

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