Constraints, Competency and Creativity in the Classroom

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Constraints define domains, specifying goal criteria and accepted means of meeting them. Competency, the ability to problem solve in a domain, depends on mastering basic constraints. Creativity follows competency, the product called creative must be both novel and appropriate to its domain. In this chapter, we discuss and demonstrate how paired constraints made very young children very competent in math and college students more creative in composition. Applications of the constraint model to other domains are also suggested. Since all readers will not be familiar with the problem-solving literature, definitions precede applications and suggestions.

Definitions

Constraint Pairs and Problem Space

The dictionary defines constraints as restrictions or confinements. In contrast, the problem-solving model presented in this paper (Reitman, 1964; Simon, 1973; Stokes, 2006, 2014b) considers constraints as pairs. One of the pair satisfies the dictionary definition – it precludes something. The other expands the definition – it directs search for and promotes a substitute. This solution-by-substitution process takes place in what Newell and Simon (1972) called a problem space. A problem space has three parts, an initial state, a goal state, and between the two, a search space in which a solution path is constructed. Table 1 presents a simplified problem space for mastering single digit addition.

Table 1 *Simplified problem space for single digit addition*

Parts	Description		
Initial State	4 + 5 = x		
Search Space	*Preclude*		*Promote*
	Guess	→	Count all
	Count all	→	Count on
	Count on	→	Count from higher addend
	Counting	→	Retrieve from memory
Goal State	Solve for x using the most efficient strategy.		

The initial state (4 + 5 = x) is the given problem. The goal (solve for x) has a criterion: solve with the most efficient strategy. In the search space, the preclude column orders addition strategies identified as least (guess) to most (retrieve) efficient by Siegler & Jenkins (1989). Each is paired (in the corresponding promote column) with its substitute (the next most efficient strategy). As the table shows, mastery of single digit addition is constraint based: less efficient strategies are precluded, more efficient ones are promoted.[1]

For tasks that require creativity, a similar set of steps applies. Here, the solution stems from a nondeterministic process: at each step there are multiple options, and choice to be made. In computational parlance, the same initial state can yield several different outcomes (Johnson-Laird, 1988) -- unlike, say, addition or multiplication, where the same input can only yield one correct outcome, via a deterministic process. The goal (generate a creative output) has a criterion: for the task at hand, find something novel and, at lower levels, useful or appropriate, and at higher ones, generative or influential.[2] In the search space, one precludes often-used, less efficient strategies with unexpected, lower-probability, hence more efficient ones.

Constraints and Domains

Domains, well-developed areas of skill, are defined by agreed-upon/recognized goal, source, subject and task constraints (Stokes & Fisher, 2005). *Goal constraints* are performance or stylistic criteria that must be met for an equation or composition to be considered correct and perhaps, at higher levels, elegant or creative.[3] S*ource constraints* provide elements to be worked with (promote) or against (preclude). *Subject constraints* specific content or motif. *Task constraints* govern materials and their application.

Competency, or the ability to problem-solve in a domain, begins with mastering the basic constraints that constitute a domain. Competency in mathematics includes counting and calculation. As a later section will delineate, competency in composition involves vocabulary and grammar. Creativity necessarily follows competency: a solution or composition must be appropriate, as well as novel, in its domain.

Applications: Constraints in Our Classrooms

Both of us applied the constraint model in the classroom. One used it to create an early math curriculum; the other, to help students become more creative in writing. For each example, we delineate the problem, the solution, the outcome, and, importantly, the next steps. The "next steps" section demonstrates how paired constraints can help refine or continue curriculum and lesson plan development.

Creating a math curriculum

The problem. The catalyst for creating the new curriculum was the place-value problem**.** The term place-value is self explanatory: the value of each digit in a multi-digit number is determined by its placement. For example, in a two-digit number, the digit on the left is a ten, the digit on the right is a one. The problem is that American children, who call the number 13 "thirteen," mistake the 3 as being of greater value than the 1. Japanese, Chinese, and Korean children, who use an explicit base-10 count and call the same number "ten-three," do not make the same mistake (Fuson, 1990; Miura & Okamoto, 2003). To show how "ten-three" fits in the Asian (Korean,

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[1] This does not mean that the less efficient strategies disappear. Rather, the distribution of strategies shifts so that the more efficient ones are used more often.

[2] Generative means leading to variations, i.e., other solutions; influential means expanding a domain (Stokes, 2006).

[3] The initial state in a problem space is a prior goal constraint. It is the preclude half of the constraint pair which promotes its substitute, the new goal constraint.

Chinese, Japanese) counts, Table 2 shows the numbers and number names from 1 through 29. Notice there are only ten number names (1 to 10), which combine to form the higher numbers. Notice too that ten appears in every number above ten: 11 is *ten*-one; 21 is two-*ten*-one.

In contrast to American children who think of numbers as chains of ones (21 means 21 ones), Asian children think of numbers as tens and ones (21 means 2 tens and 1 one). For children who think this way, place-value is not a problem.

Table 2 *Explicit base-10 count.*

	Ones		Tens		Twenties
		10	*ten*	20	two-*ten*
1	one	11	*ten*-one	21	two-*ten*-one
2	two	12	*ten*-two	22	two-*ten*-two
3	three	13	*ten*-three	23	two-*ten*-three
4	four	14	*ten*-four	24	two-*ten*-four
5	five	15	*ten*-five	25	two-*ten*-five
6	six	16	*ten*-six	26	two-*ten*-six
7	seven	17	*ten*-seven	27	two-*ten*-seven
8	eight	18	*ten*-eight	28	two-*ten*-eight
9	nine	19	*ten*-nine	29	two-*ten*-nine

The solution. The proposed solution (to the place-value problem and by extension to multi-digit addition and subtraction problems) was not simply to introduce an explicit base-10 count, but to embed it in a curriculum that taught children to think mathematically, in large meaningful patterns. Table 3 shows the problem space. The initial state was current curricula. The goal state, a new curriculum, had a criterion: thinking in numbers, symbols, and patterns.

Table 3 *Problem Space for New Math Curriculum*

Parts	Description		
Initial State	Current Curricula		
Search Space	*Preclude*		*Promote*
	English language count	→	Explicit base-10 count
	Non-numeric	→	Numbers, symbols, patterns
	Multiple manipulatives	→	Single manipulative
	Split practice	→	Continuous, focused practice
Goal State	New curriculum Criterion: thinking in numbers, symbols, and patterns		

The first pair (which involve source constraints) precluded the English language count and promoted an explicit base-10 count. The next three are task constraints designed to further satisfy the new goal criterion. Non-numeric meant videos with cartoon characters, work sheets with stories, and word problems that can distract children from the strictly numeric. The single manipulative was meant, like the abacus, to make base-10 numbers and patterns tangible and concrete.

Figure 1 shows the manipulative, called the count-and-combine chart, with the numbers 1 through 10. Notice that 10 is represented both as 10 "one" blocks and as a single "ten" block.

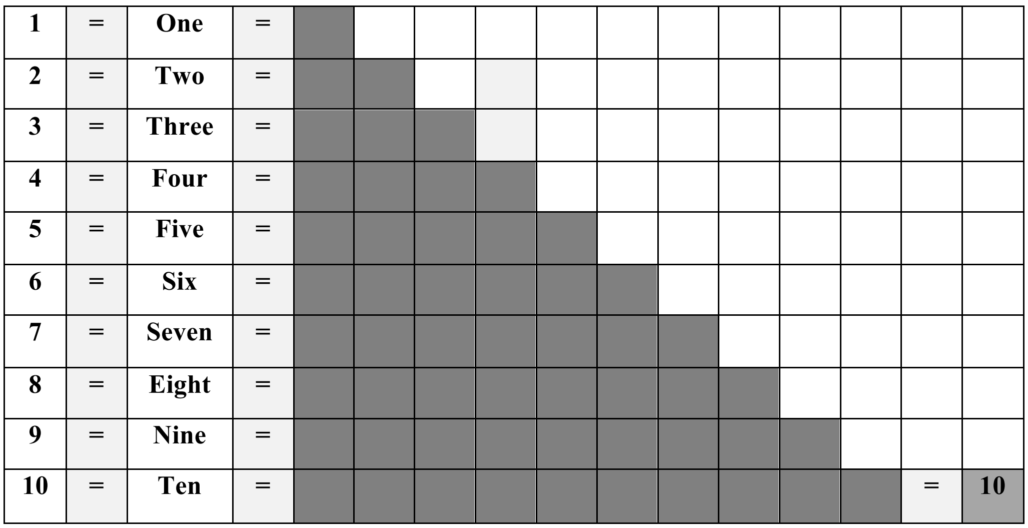

Figure 1 *Count-and-combine chart for numbers one to ten*

The numbers, number names, symbols, and colored boxes representing ones are all moveable. Children began by reciting the rows. The top row is read "number one same as word one equals one block." They continued by recombining the blocks creating addition combinations for each number. Figure 2 shows two of eight possible combinations for the number 4.[4] As the numbers increased in value, so did the possible combinations.

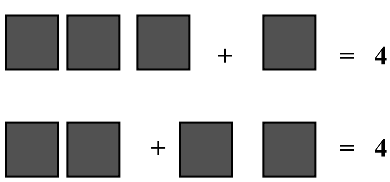

Figure 2
Two addition combinations for 4.

Figure 3 shows a count-and-combine chart with the numbers 10 to 15 (ten-five). As in Figure 1, ten is represented as a unit, by a single block marked "10." There are other similarities. In each chart, the block pattern mirrors the reiterations in the count: four equals 4 one blocks; ten-four equals one 1 ten block and 4 one blocks.

[4] The six combinations are : 4, 2 + 2, 3 + 1, 1 + 3, 2 + 1 + 1, 1 + 1 + 2, 1 + 2 + 1, and 1 + 1 + 1 + 1.

Later on, the children learned that 44 (four-ten-four) equals 4 ten blocks and 4 one blocks. They also learned to add tens to tens, before adding ones to ones, and to take tens away from tens, before taking ones from ones. To clarify what "take away" meant, children physically took away the same number of ten and one blocks from either side of the minus sign. The blocks left over were the remainder.

10	=	**Ten**	=	**10**										
11	=	**Ten-one**	=	**10**										
12	=	**Ten-two**	=	**10**										
13	=	**Ten-three**	=	**10**										
14	=	**Ten-four**	=	**10**										
15	=	**Ten-five**	=	**10**										

Figure 3 *Count-and-combine chart for numbers 10 to 15*

The outcome. The children were tested at the end of the school year. Did those using the new curriculum learn more math than a comparison group using the district curriculum (*New Jersey Mathematics: Scott Foresman – Addison Wesley*)? Yes. On place-value, single- and double-digit addition and subtraction, and number line estimation, children taught with the new curriculum (*Only the NUMBERS Count©)* outperformed those in the comparison group (Stokes, 2013, 2014a). On number line estimation, they performed as well as Chinese students of the same ages (Siegler & Mu, 2008). In sum, they became highly competent at thinking in numbers, symbols, and patterns.

The next step. The next step was expanding the curriculum to second grade. The problem became how to teach multiplication and division. The solution was again derived from the Asian classroom. This time we *precluded* our multiplication table and *substituted*, in its place, the Chinese table. Like the count-and-combine charts, the table is chanted. The chant defines the key difference in the learning: children do not count ("two, four, six …"), they multiply ("two-twos are four, two-threes are six …"). The table itself is much simpler than ours. The simplicity suggested two new uses: to visually demonstrate the "flips"[5] (2 x 3 is the same as 3 x 2) in division and, more importantly, how division un-does multiplication. This expansion is being piloted as this chapter is being written. So far, so good.

Making Composition More Creative

The problem. When an essay or a presentation for work is due, many of us - children and adults - find ourselves stuck in old "solutions." When a friend's birthday is coming up, we struggle to create a message that says what we mean. What makes that new Word document, white sheet of paper, or blank greeting card so intimidating? There are several possibilities. One, there are too many possible solution paths: choice is stressful. Two, without

[5] This is the term children already used to indicate that addends could be reversed, i.e., 2 + 3 is the same as 3 + 2.

constraints we all repeat what has worked best in the past: familiar solutions surface sooner than novel ones (Maltzman, 1960; Runco, 1986; Ward, 1969), the most-traveled path prevails.[6]

Language in general and figurative language in particular (Glucksberg & Haught, 2006; Haught, 2013; 2014) is a prime example of creativity, which operates within a given set of constraints. But, you ask, what about artistic freedom? Indeed, an unconstrained field does invite free, unencumbered exploration. By chance alone, you *might* stumble upon an unexpected, fortuitous turn of phrase. But most of the time, the most-traveled path will prevail, drawing you into prosaic, formulaic phrasing.

The problem is obvious: how can we make composing more creative?

The solution. The strategy we suggest is straightforward: seek and embrace constraints. Remember, constraints do two things. They limit search along those predictable (albeit reliable) old paths, precluding widely-used associations. They direct search along less-traveled paths, promoting in-depth exploration of unexpected, surprising associations. Table 4 presents a generalized problem space for creative composition. The initial state is the clichéd, the goal is the creative. To actually reach the goal, each of the pairs must be further specified. For example, imagine the cliché to be precluded is "Once upon a time…." The opening suggests, of course, a fairy tale. Substituting "3 am, again…" suggests several quite different tales: one about insomnia, another about surveillance, a third about what?

Table 4 *Problem Space for Creative Composition*

Parts	Description		
Initial State	Clichéd Composition		
Search Space	*Preclude*		*Promote*
	Existing, clichéd associations	→	Novel, unexpected associations
	Too large a search space	→	Narrower, more focused search space
	Superficial exploration of many alternatives	→	In-depth exploration of fewer alternatives
	'Blank page'-induced writer's block	→	Constraint-induced creative writing
Goal State	Creative Composition		

The outcome. Constraints work especially well for professionally literary composition. Members of OULIPO (the Ouvroir de Littérature Potentielle), self-impose formal and combinatorial constraints on their writing. For example, they have successfully excluded specific letters -- see Perec's (1969) 300-page novel, which excluded the letter E --, allowed a single vowel, and replaced each noun with the seventh noun after it in the dictionary[7]. Theodore Geisel, well-known as Dr. Seuss, wrote *Green Eggs and Ham* in response to a challenge: write a children's book using only fifty words. In his novels (one of which[8] won a Nobel Prize), Jose Saramago precludes

[6] This is called operant conditioning.
[7] For more examples and a history of OULIPO, see Becker (2012)
[8] *The History of the Siege of Lisbon*

quotation marks around conversations. The constraint makes the reader pay very close attention to the phrasing that identifies a speaker.

What about the non-professional writer? Do constraints work as well? It seems so. When college students were asked to generate creative sentences in response to pictures or words, their outputs were judged more creative for pictures (Haught, in press). Pictures proved more provocative, more suggestive than words, "worth a thousand" of them, as the saying goes. For example, pictures of a LION, a STRAWBERRY, and a HARP produced sentences like "The harp had a strawberry-colored lion carved in its post." The words alone led to sentences like "I ate a strawberry while listening to harp music and watching a lion at the zoo." In short, the search space was constrained by the visual representations, which in turn guided the construction of the sentences.

College students also wrote more creative rhymes for a special occasion - a birthday or anniversary - when their task was constrained by including a given noun (Haught, in press). You should try this yourself. How would you say *I love you* in a two-line rhyme that must include the noun *vest*? How could you express *I am sorry* in a rhyme that includes the noun *shirt*? Here are what two participants wrote:

We belong together like a sweater and vest.
"I love you" and I'll write it across my chest.

Here is a wool shirt for you to keep.
I am sorry, and so is the sheep.

Interestingly, even after removing the constraint of a given noun, the rhymes were more creative. Mere practice with a constraint seems to help, even immediately after it is explicitly removed.

In another study, preliminary results indicate that rhymes required to start with a given letter of the alphabet were more creative than those written without the constraint. The first letter appears to have acted as an anchor, precluding search for rhymes starting with any of the other twenty-five letters of the English alphabet, promoting more efficient search within a given, narrower field.

The next step. We have examined externally imposed (the student examples) and internally imposed constraints (the professional writers). The pair pose two interesting questions. One, can we teach students to use their own constraints? Two, can we teach students to use the professional writers constraints?

To answer the first question, college students were instructed to write down the first concrete nouns that came to mind (the internal constraint), and then incorporate those nouns in greeting-card type rhymes (the external constraint). The internal constraint led to more creative greetings than those written by students using only the external constraint. To convey *Thank you* in a rhyme that also incorporates a self-generated word (*sunflower*, *dog)*, two participants wrote:

Thank you for making my life a beautiful <u>*sunflower*</u>*;*
You sure do have some magical power.

Thank you <u>*dog*</u>*;*
Stay solid like a log.

The external constraint alone yielded mostly uninspired rhymes, of the sort:

Thank you for being so great,
It's something I really appreciate.

But, interestingly, once again, when students first worked with both constraints (external and internal), and then with only the external constraint, their rhymes in the latter exercise were more creative than when they had never been introduced to an internal constraint. Students seem to have continued to seek constraints, after being initiated into the practice of using them, which they liked and which enhanced creativity.

To answer the second question, students rewrote their own short memoirs using the constraints described and used by A.S. Byatt, Italo Calvino, and Milan Kundera. The students were surprised at how easy it was to "try on" another writer's constraints, and importantly, at how much more imaginative their stories had become. More next steps are suggested in the next section.

Suggestions: Using Constraints in Your Classroom

For tasks that are largely unrestricted, especially those that require creativity, imposing constraints can help. We include several examples.

- In literary composition, the challenge of developing an essay on a given theme can be overcome by anchoring it with a set of semantic (e.g., include a given set of words) or formal (e.g., start with a given letter of the alphabet) constraints.
- Again in composition, teach your students how to create their own constraints. They can begin by practicing (as shown in the preceding section) with combined internal (student-generated) and external (teacher-generated) constraints. They can also practice using constraint pairs to (1) identify elements in their current writing style, (2) pick specific elements to preclude, and (3) specify substitutes.
- In developing vocabulary, parsing sentences can provide a useful structure. Once the parts of the sentence are diagrammed, students can be asked to suggest multiple substitutions for nouns, verbs, adjectives. How many ways can this sentence be expanded, made more specific, more interesting?

Sally /	baked /	cookies
	/today	/chocolate-chip
		/twenty

- In art, a set of small canvas boards with the same cartoon (a subject constraint) to be painted in different styles (a task constraint) or in different color combinations (also a task constraint) can be a catalyst for creativity. The search space could be narrowed further by specifying a style or palette the student does not usually employ.
- In history, a seemingly dry series of texts, dates, people, and events can come to life within the framework of a beautiful constraint: have the students immerse themselves and become active participants in critical events like the trials of Socrates or Anne Hutchinson. "Reacting to the Past," a program created by Mark

Carnes at Barnard College, uses just this constraint to facilitate student engagement and improve critical thinking, problem solving and communication skills (Carnes, 2014).

Not to be ignored are those inevitable classroom constraints (time, technology, assessment needs) that are not obviously occasions for incrementing creativity. Our suggestion is to make these constraints the "preclude" half of a constraint pair. What can be promoted as a direct result of such a constraint? Let's focus on testing, on using a required assessment tool for pedagogical purposes. Research shows that there are advantages to testing. Test-enhanced learning refers to the finding that taking a test on studied material produces both better learning and retention than re-studying the material for the same amount of time as the test (Roediger & Karpicke, 2006; McDaniel, Roediger, & McDermott, 2007). So, some suggestions for all testing on all topics:

- Retrieving is more effective than re-reading. Test frequently.
- Give immediate feedback, which has also shown to enhance competency (Brosvic & Epstein, 2007).
- Incorporating "teaching-the-test" into regular lesson plans. This will make your teaching more variable and more effective (Stokes, 2013).
- Frame questions that preclude rote memorization and promote meaningful understanding.

Whether your challenge is enhancing competency or creativity, think in terms of paired constraints. Start by filling in the blank problem space below. Identify the initial state and the goal state. Define what each constraint pair precludes and what it promotes, and remember, every solution path starts with a single substitution.

Table 5 *Problem space for* ________________________

Parts	Description	
Initial State		
Search Space	*Preclude*	*Promote*
Goal State		

Conclusions and Concluding Caveats

Our conclusions are two.

First, paired constraints are tools that can help teachers *design* curricula and lessons to help students develop competency and creativity. Second, re-iterative use of paired constraints (to *re-design* that lesson plan) can help keep your thinking and your teaching new.

Our caveats are also paired. Learning to use paired constraints is like all learning – it takes time and practice. Persistence pays off. The payoff could be finding a new path to a creative solution. Faced with a frustrating outcome, don't cut exploration short and go back to where you started. Chances are you'll only embark on another, equally frustrating search down yet another – or, sometimes, the same! – well-traveled path.

Take your time. Practice.

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