Abstract Title Page
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Title: Aligning the Structural Components Across Learning Tasks of Case Comparisons

Author(s):
Louis Alfieri
Timothy J. Nokes
Christian D. Schunn

Abstract Body

Limit 4 pages single spaced.

Background / Context:

Description of prior research and its intellectual context.

Analogous thinking has been commonly discussed as being an inherent and distinguishing characteristic of human cognition (e.g., Gentner, 2010; Goldstone, Day, & Son, 2010; Holyoak, in press; Rittle-Johnson & Star, in press). Gentner (2003) has argued that as part of the human cognitive toolbox, comparison accompanied by the relational language to support it has rocketed humanity to the top of the natural hierarchy. “Although we are not the only animal with analogical ability, the difference in degree of ability is so great that it stands as a qualitative difference” (Gentner, 2003, p. 219). A core component of analogical thinking is the comparison of two cases to one another and the alignment and mapping of features from one case to another. Such comparisons have been shown in laboratory experiments to be a powerful learning practice compared to studying each example separately (e.g., Gentner, Loewenstein, Thompson, & Forbus, 2009; Gerjets, Scheiter, & Schuh, 2008, Experiment 2; Mundy, Honey, & Dwyer, 2009, Experiment 2; Richland & McDonough, 2010, Experiment 2; etc.).

As a way of appropriating this informal, experiential learning that is at least partly driven by analogous thinking (e.g., categorization; Gentner & Holyoak, 1997), numerous formal learning situations have been designed with case comparisons to teach more traditional subject matter within classrooms (e.g., Gadgil & Nokes, 2009; Gentner, Loewenstein, Thompson, & Forbus, 2009; Mason, 2004; Michael, Klee, Bransford, & Warren, 1993; Nagarajan & Hmelo-Silver, 2006; Rittle-Johnson & Star, in press; Schwartz & Bransford, 1998; etc.). Analogous thinking in the form of learning tasks requiring case comparisons is arguably a form of scaffolded constructivism that is more than merely active (Chi, 2009) because it demands from the learner a level of engagement that goes beyond the learning materials in order to notice the underlying connections between them. The appreciation of those underlying connections potentially leads to learning (Gentner, 2010). In terms of the learning environments outlined by Chi, a learning task of case comparisons is not only active but also constructive (e.g., structural alignment, role-based relational processing, etc.; Gentner, 2010; Holyoak, in press, respectively) because it provides learners with two instances and asks them to construct their own understanding that serves to bridge the cases in the most consistent way.

Within the case comparisons literature, there is a great variety in the ways in which cases are instantiated and tested both in laboratory and classroom settings. Some of these variables can be considered process variables because they are related to the learners’ processions through learning tasks. Process variables include the following: the qualities of cases, the types of instructions that introduce learners to the tasks, the scaffolds in place to assist learners, etc. Other variables can be considered generalizability variables: the domain of the subject matter (e.g., math, science, etc.), the age and experience levels of participants, etc. Thus, when considering the efficacy of case comparisons and the variety of methodologies that have previously investigated them, a meta-analysis seemed appropriate to get a better of sense of where the field is, how well our model of this learning process (see Practice section below) fits the patterns observed, and how future investigations could be designed best to answer remaining questions. Recently, Rittle-Johnson and Star (in press) requested a synthesis across studies in hopes of reaching a more comprehensive understanding of how comparisons aid learning and it seems that we are the first to attempt to meet that request.

Purpose / Objective / Research Question / Focus of Study:

Description of the focus of the research.

The current meta-analysis will focus on the following three questions: 1) Overall, are case comparisons a method of instruction that leads to outcomes that are superior to other forms of instruction? 2) To what extent are such findings generalizable to all learners in all domains and situations? 3) What characterizes better case comparisons learning tasks and which conditions of our process variables fall short? Furthermore, the current study presents a new methodology for investigating potential moderators through meta-analytic techniques by investigating to what extent general trends are maintained across levels of other correlated variables.

Setting:

Description of the research location.

The sample includes both classroom-based and laboratory-based studies and setting has been included as a potential moderator. Please see Research Design section below.

Population / Participants / Subjects:

Description of the participants in the study: who, how many, key features, or characteristics.

The sample includes studies of learners of all ages and experience-levels and both age and experience were included as potential moderators.

Intervention / Program / Practice:

Description of the intervention, program, or practice, including details of administration and duration.
For Track 2, this may include the development and validation of a measurement instrument.

A model of the learning process.

A process model is shown in Figure 1. Case comparisons begin with the focused, effortful consideration of the cases required to detect and appreciate commonalities (Seifert, McKoon, Abelson, & Ratcliff, 1986). The similarities between the cases (local identity matches), the instructions of the task (to compare, to state similarities, etc.), or both serve to highlight the alignable target elements or key features which can then be aligned toward structural consistency (Gentner, 2010; Gentner & Markman, 1997). To maximize their alignability and minimize the cognitive demands of the comparison task, cases should be presented simultaneously instead of sequentially. The alignment of the target elements of the cases leads to two general outcomes.[1] Firstly, it shifts attention away from extraneous elements that no longer seem important because they do not align with any comparable elements in the other case. Secondly, it leads either to schema creation (if the unifying principle/concept is novel to the learner) or to schema activation (if the learner has previous experience on which to build). The resultant consideration of only the target elements, which by this time in the process have a more abstracted form, would consequently reduce learners' working memory demands and therefore cognitive load because only the features important to the common system shared by the cases would need to be maintained instead of the learner having to maintain all of the details of both cases. This reduction in cognitive load would allow for subsequent consideration (and encoding) of the cases to meet the demands of the systematicity principle (i.e., a bias to prefer deeper relations; Gentner, 2010). What seems uncertain is whether as a result of the studied cases being interpreted as parts of a unifying schema, long-term memory includes only the abstracted schema derived from comparisons, or includes both the abstracted schema and memory for individual cases. Whichever the case, the abstracted long-term memory representation (i.e., schema;

[1] Whereas Gentner (2010) distinguishes four types of learning outcomes, for the purposes of reaching a general process model that can include our entire sample within this meta-analysis we are going to focus on two more general outcomes. We concede that the four types that she has outlined do fit within our model but given the limited information provided within articles, it seemed best to remain conservative with two.

Forbus, Gentner, & Law, 1994; Hintzmann, 1986) can potentially lead learners to encode newly encountered cases in light of that schema (Medin & Ross, 1989) or to have greater ease in retrieving that schema for a transfer application (Genter, Loewenstein, Thompson, & Forbus, 2009).

- Please insert Figure 1 here. -

When the learner encounters analogous test problems/cases, especially those that are part of the same setting (class or experiment) as the study phase, the learner's schema for such analogs is activated by the presence of the abstracted target elements that were identified during the learning activity and are now part of the schema[2]. The alignment of the new case's elements to those within the schema then facilitates a correct solution or the appropriate consideration of the target concept as part of the studied conceptual category. Thus, case comparisons could potentially lead not only to correct solutions of target problems on post-tests but also more generally to changes in how learners encode future analogous cases and/or related subject matter, as is suggested by the preparation for future learning (PFL) literature among others (e.g., Medin & Ross, 1989; Bransford & Schwartz, 1999).

Research Design:

Description of the research design.

Table 1 lists the 15 potential moderators for which we coded. Again, some were process variables whereas others were generalizability variables.

- Please insert Table 1 here. -

Data Collection and Analysis:

Description of the methods for collecting and analyzing data.

Relevant studies were identified through computerized literature searches on the *Web of Science*, *PsycInfo*, *ERIC*, and *Google Scholar* using terms like *analogical comparisons, structural alignment, schematic learning*, etc., from citations within other articles, and email correspondences with authors. The selection criterion was that studies had to test directly for differences between a condition employing case comparisons and a condition that involved sequential case study, single case study, non-analogous case study, a control/baseline group (no study phase), or more traditional instruction (lecture and/or problem solving). Inter-rater reliability on the coding of our 15 potential moderators led to an overall kappa of .80. Analyses were conducted both at the level of *experiments* (i.e., average effect sizes across measures of single samples of learners) and at the level of *tests* (i.e., each effect size of all measures entered individually so that potential moderators could be investigated).

Findings / Results:

Description of the main findings with specific details.

Using the CMA Version 2 program (Borenstein, Hedges, Higgins, & Rothstein, 2005), a random effects analysis of 57 experiments (336 tests) revealed an overall medium effect size favoring case comparisons learning situations, d = .60 (95% CI [.47/.72]). See Table 2. The effects were found to be heterogeneous across samples, $Q(56) = 136.74$, $p < .001$, with 59% of the variability among effect sizes caused by true heterogeneity between studies, $I^2 = 59.05$. Consequently, we were justified in violating statistical assumptions of independence to investigate moderators at the level of tests. In order to rule out potential publication bias, we calculated fail-safe Ns with alphas set to .05, two-tailed. At the levels of experiments and tests,

[2] Of course, this is only one possible explanation for how the schema derived from compared cases is activated during testing.

respectively 2,795 and 5,244 unpublished studies would be needed to alter the results so that the effect would no longer be statistically significant.

- Please insert Table 2 here. –

Of the 15 potential moderators investigated, five were found to moderate findings consistently: content, principle, features, objective, and lag. See Table 3. Although all five were correlated with other variables, those trends generally held across levels of the correlated variables with few exceptions. Age, setting, experience, and the type of case comparisons learning task did not moderate effects; all showed comparable benefits of case comparisons tasks over other types of instruction.

- Please insert Table 3 here. –

Further analyses revealed that although some levels of our potential moderators were found to moderate effect sizes that those trends did not hold up when we examined them across levels of the variables with which they were correlated. The moderators of domain, context, and dependent measure all fit into this group. See Table 4. Furthermore, publication rank (publication), OLS (other learning situation), and duration have to be considered tentatively because of lower power in some of their levels.

- Please insert Table 4 and Table 5 here. –

Conclusions:

Description of conclusions, recommendations, and limitations based on findings.

Analyses indicated that the effects are largely generalizable. Although few studies investigated adolescent-aged learners, within this sample case comparisons seems beneficial to learners of all ages and of all levels of experience. The marginal difference found between the effect sizes in math and science do not hold up under all circumstances. In studies published in second-tier journals, effect sizes in math and science are functionally equivalent. Effect sizes in the math, science, and other domain are all equivalent when the instructional design is brief and when learners are familiar with the subject matter. Effects also seem consistent in both laboratory and classroom settings but the former tend to be brief in duration and the latter tend to be long (i.e., strongly correlated with duration).

When we consider the findings for our process variables, several features of case comparisons tasks stand out. Learners benefit most when they are asked only to find the similarities between cases, when they are provided with the features of at least one of the two cases, and when the principle is provided after the case comparisons task. Finding only the similarities helps learners to align the cases (Gentner, 2010) potentially because doing so is the most focused form of case comparisons. Learners can easily be distracted by differences and not have the same amount of study time to appreciate fully the shared common system. Moreover, having the features of at least one case provided, potentially acts as scaffolding for the learner who might otherwise be uncertain as to how to align the two cases. Presenting the principle after the task helps to confirm the learner's potentially tentative understanding (Holyoak, in press). In a related pattern, the more immediate the testing, the better performances are but it is not only the forgetting curve at work (Ebbinghaus, 1913). It seem that the tentative nature of learners' abstractions also factor in because there is no effect of the lag in testing when we only analyzed the tasks that included the presentation of the principle after. Such findings support claims made within the preparation-for-future learning (PFL; Bransford & Schwartz 1999; Schwartz & Bransford, 1998) literature.

Overall, case comparisons tasks seem to be a promising way to get learners to be constructive and consequently, to learn.

Appendices

Not included in page count.

Appendix A. References

References are to be in APA version 6 format.

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References marked with an asterisk indicate studies included in the meta-analysis.

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Appendix B. Tables and Figures

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Table 1

Levels of Potential Moderators within the Coding Scheme

Moderator	Definition and/or Examples
Publication	
Top-tier	Impact factor ≥ 2
Second-tier	Impact factor < 2
Conference	Proceedings since unpublished
Domain	
Science	E.g., states of matter and energy transfer (Mason, 2004)
	E.g., schema and encoding concepts (Schwartz & Bransford, 1998, E1-E3)
Math	E.g., solving applied algebraic problems within different domains (Gerjets, Scheiter, & Schuh, 2008, E2)
	E.g., solving algebraic problems (Rittle-Johnson & Star, 2007)
Other	E.g., getting a bead out of a cylinder (Chen & Daehler, 1989)
	E.g., negotiating contracts (Gentner, Loewenstein, & Thompson, 2004, E1)
Age	
Children	≤ 12 years-old; through 6th grade
Adolescents	Between 13 and 17 years old; from 7th through 12th grades
Adults	≥ 18 years-old; undergraduates
Experience	
Little	Little to no experience with subject matter
Familiar	At least some experience with the content prior or concurrent to study
Extensive	Professionals in the same or a related field
Setting	
Classroom	Participation was part of a class and learners' performances impacted their grades
Lab	Participation was not part of a class and learners' performances did not impact their grades
Content	
Conceptual	Terms, definitions, categorizations
	E.g., schema quality and the quality of a recalled personal experience involving a contingency contract (Gentner, Loewenstein, & Thompson, 2004, E1)
Procedural	Executing steps to a solution
	E.g., implementation of a contingency contract (Gentner, Loewenstein, & Thompson, 2004, E1)
Perceptual	Perception of relationships among stimuli
	E.g., perceiving cross-mapped objects (Markman & Gentner, 1993)

Moderator	Definition and/or Examples
Type of Case Comparisons	
Prompted	Learners compared cases but were not provided with instructions / questions that directed their attention to structural components.
	E.g., with two objects placed side-by-side, learners were asked, "Can you see why these are both [jiggies]?" (Christie & Gentner, 2010, E1)
	E.g., learners described similarities between two cases and rated that similarity on a 7-point scale (Gick & Holyoak, 1983, E4)
Guided	Learners were asked questions or were given instructions that directed their attention to structural components.
	Eg., provided with two solved analogs, learners were asked to explain the common critical insight and parallels, and then to match five elements between the two (Kurtz & Loewenstein, 2007, E1)
	E.g., with worked examples presented side-by-side, learners explained how the two solutions differed (Star & Rittle-Johnson, 2009)
Context	
Rich	Cases contained extraneous details / information.
	E.g., videotaped sessions of formative assessments (Nagarajan & Hmelo-Sliver, 2006)
	E.g., textually presented scenarios resolved with contingent contracts (Gentner, Loewenstein, Thompson, & Forbus, 2009, E2)
Minimal	Cases were created in ways that highlighted structural components and that only including important details.
	E.g., worked examples of multistep mathematical computations (Rittle-Johnson & Star, 2007)
	E.g., textual presentations of only relevant information paired with diagrammed organizations of those facts (Gentner, Loewenstein, & Thompson, 2003, E2-3)
Principle	
Before	Principle was presented before the case comparisons task
After	Principle was presented after the case comparisons task
Not	Principle was not presented
Features	
Generated	Learners were not provided with the corresponding features.
Provided	Learners were provided with features for at least one of the cases.
Objective	
Similarities	Learners were only asked to find similarities between cases.
Differences	Learners were only asked to find differences between cases.
Both	Learners were asked to find both similarities and differences.
Duration	
Brief	Single sessions of less than one hour
Long	Multiple sessions and/or a session of more than one hour

Moderator	Definition and/or Examples
Other Learning Situation (OLS)	
Control	No study phase / baseline
Nonanalogous	Learners either simultaneously compared two cases or sequentially studied cases but in all conditions some of those cases were not analogs.
Sequential	Learners studied the same cases as the case comparisons learners but did so sequentially instead of simultaneously.
Single Case	Learners were presented with only one analogous case to study.
Traditional	Problem solving and/or lecture
Dependent Measure (DM)	
Near	For conceptual content, learners had to recognize or apply studied concepts without adaptation.
	For procedural content, learners had to transfer a previously studied, intact core solution.
Far	For conceptual content, learners had to make inferences or draw analogies between studied concepts and new concepts.
	For procedural content, learners had to modify studied core solutions to accommodate the variables or features within the new case.

Table 2

Summary of Effect Sizes

	Cohen's *d*	95% CI	*Z*	*Q*	*k*	I^2
Fixed						
Experiments	.45	.38 / .53	12.10*	136.73*	56	59.05
Tests	.37	.34 / .41	23.61*	1,048. 47*	335	68.05
Random						
Experiments	.60	.47 / .72	9.29*			
Tests	.50	.44 / .56	16.74*			

*p < .001

Table 3

Moderators Found to be Consistent Across Correlated Variables

Moderator	Cohen's *d*	95% CI	*Z*	*Q*	*k*
Content					
Conceptual	.54	.46 / .61	13.48**		210
Procedural	.40	.31 / .49	8.55**		99
Perceptual	.72	.49 / .96	6.00**		24
				8.89*	2
p < .016†	Procedural	Perceptual			
Conceptual	5.03	2.15			
Procedural		6.27†			
Principle					
Before	.23	.13 / .33	4.38**		73
After	1.18	.93 /1.44	9.09**		28
Not	.53	.46 / .59	15.80**		232
				53.39**	2
p < .016†	After	Not			
Before	46.03**	22.32**			
After		24.03**			
Features					
Generated	.42	.35 / .49	11.42**		224
Provided	.66	.57 / .75	14.35**		110
				16.63**	1
Objective					
Similarities	.68	.60 / .75	17.83**		197
Differences	- .19	-.30 /-.07	-3.06*		6
Both	.28	.20 / .36	6.66**		130
				154.33**	2
p < .016†	Differences	Both			
Similarities	146.21**	48.60**			
Differences		40.08**			
Lag					
Immediate	.57	.50 / .64	16.50**		254
Same Day	.44	.25 / .64	4.39**		21
Subsequent	.22	.11 / .34	3.94**		58
				27.32**	2
p < .016†	Same Day	Subsequent			
Immediate	1.55	27.21**			
Same Day		3.57			

*$p < .05$, **$p < .001$

Table 4
Moderators that Varied Between Correlated Variables

Moderator	Cohen's *d*	95% CI	*Z*	*Q*	*k*
Domain					
Science	.72	.36 / 1.08	3.94**		10
Math	.23	.05 / .42	2.44*		9
Other	.66	.50 / .81	8.24**		35
				12.93*	2
$p < .016$†	Math	Other			
Science	5.51	.09			
Math		11.46†			
Context					
Minimal	.34	.26 / .43	7.74**		128
Rich	.60	.52 / .67	15.52**		206
				18.84**	1
DM					
Near	.52	.46 / .58	16.11**		287
Far	.34	.20 / .48	4.64**		47
				5.08*	1

*$p < .05$, **$p < .001$

Table 5

Moderators that Suffer from Low Power

Moderator	Cohen's *d*	95% CI	*Z*	*Q*	*k*
Age					
Children	.94	.48 / 1.39	4.04**		9
Adolescents	.34	- .01 / .68	1.92		4
Adults	.53	.42 / .64	9.55**		41
				4.27	2
Publication					
Top	.59	.41 / .76	6.50**		30
Second	.73	.50 / .95	6.31**		19
Conference	.28	.05 / .51	2.38*		5
				7.85*	2
p < .016†	Second	Conference			
Top	.92	4.33			
Second		7.43†			
OLS					
Control	.69	.58 / .80	12.57**		63
Nonanalogous	.82	.55 / 1.08	6.06**		23
Sequential	.37	.31 / .44	11.11**		201
Single Case	.92	.57 / 1.28	5.11**		16
Traditional	.49	.24 / .74	3.87**		29
				37.59**	4
p < .005††	Non	Sequ	Single	Trad	
Control	.79	24.60††	1.56	1.98	
Non		10.35††	.23	3.06	
Sequential			9.08††	.87	
Single				3.81	
Duration					
Brief	.58	.43 / .72	7.76**		39
Long	.66	.40 / .91	5.00**		16
				.27	1

**p* < .05, ** *p* < .001

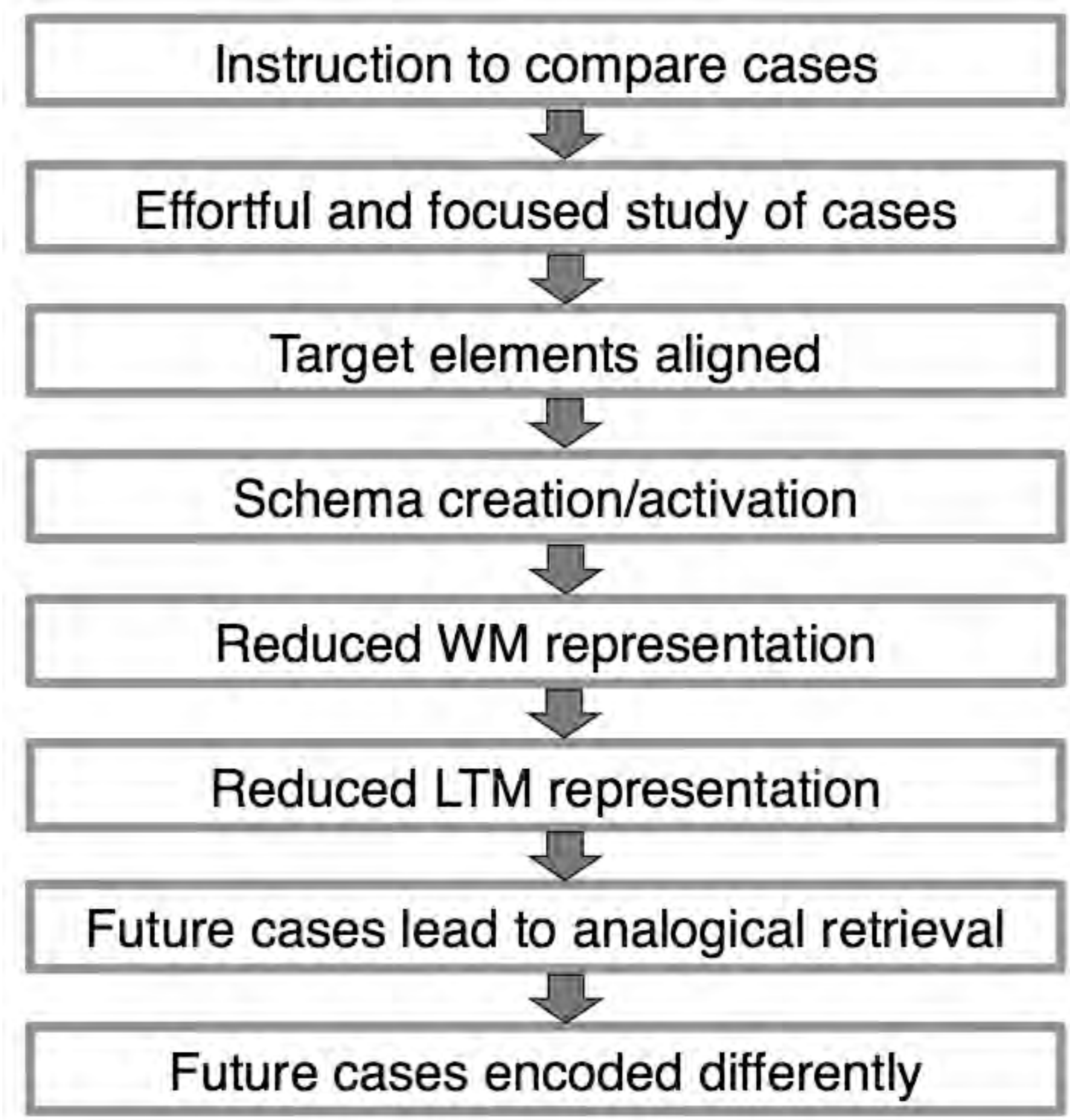

Figure 1. A model of the process of case comparisons learning tasks.