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Dynamic Explanatory Coherence with Competing Beliefs: Locally Coherent Reasoning and a Proposed Treatment

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Abstract

Two experiments address dynamic aspects of modeling the Theory of Explanatory Coherence (TEC) and the predictive utility of its auxiliary "competition principle." The principle suggests that people should infer an inhibitory relation between beliefs that *independently* explain another belief. We compare two connectionist TEC implementations, ECHO1 and ECHO2, as only ECHO2 uses the competition principle. In Study 1, subjects read text segments that gradually biased them toward understanding Berlin's true location. In Study 2, past informal physics data are more molecularly and dynamically reanalyzed and remodeled. Results show that (a) the competition principle needs refinement and does not necessarily improve ECHO's account of students' belief ratings, (b) the principle probably overestimates subjects' abilities to infer and/or incorporate competitions among (especially unfamiliar) beliefs, and (c) subjects' local (nonglobal) coherence, likely due to processing limitations, helps account for recency-related (and other) observed effects. From these and past experiments' insights, we designed a "reasoner's workbench" to help students explicate and evaluate arguments more globally and rationally.

Introduction

The Theory of Explanatory Coherence (TEC; Ranney & Thagard, 1988; Thagard, 1989) offers a plausible account of how people evaluate hypotheses, evidence, and other propositions regarding various situations. Several pieces (e.g., in Giere, 1992) discuss the theory and its connectionist implementation as a model (ECHO), yet only a few (see Schank & Ranney, 1992) have explicitly tested the model in other than *ex post facto* ways. The present paper extends predictive work by those (e.g., Schank & Ranney, 1991; Read & Marcus-Newhall, in press) who have evaluated and discerned the descriptive utility of various philosophical principles that largely comprise TEC. (See Ranney, in press-a; cf. Schank & Ranney, 1992, with predictions from Ranney & Thagard, 1988.) We also focus more closely on the dynamics of students' explanatory coherence than in past work (cf. Schank & Ranney, 1991). Further, we employ divergent methods across two experiments to assess the role of familiarity (or the "ownership" of one's reasoning) with respect to subjects' ability to maintain relatively global (as opposed to local) explanatory coherence (Ranney, 1987/1988, in press-a, in press-b). Finally, we have integrated these findings in the design of our "reasoner's workbench" to teach coherent argumentation.

TEC's Principles (including Competition)

TEC incorporates many of the most acclaimed philosophical principles for scientific (and arguably, nonscientific) reasoning. They are put forth as a system for governing the explanatory ways in which proposed entities (i.e., propositions) "cohere" (mutually support) or "incohere" (mutually conflict). As they are described more fully and formally elsewhere (e.g., Ranney & Thagard, 1988; Schank & Ranney, 1991; Thagard, 1989 & 1992), we offer a palimpsest of relevant principles here: (1) Coherence and incoherence are each symmetric relations between pairs of propositions. (2) Hypotheses that (jointly) explain a proposition cohere with (each other and) the explained proposition. (3) Simplicity: A belief's plausibility is inversely influenced by the number of cohypotheses it needs to help explain a proposition. (4) Data Priority: Results of observations, e.g., evidence and acknowledged facts, have a degree of acceptability on their own. (5) Contradictory hypotheses incohere. (6) Competition: Two propositions incohere/compete if they explain a third proposition (an explanandum), yet are not themselves explanatorily related (cf. Harman, 1989). (This principle is optionally invoked below.) (7) A proposition's acceptability depends on its coherence with its embedding system of propositions; its acceptability increases as it coheres more with other acceptable beliefs and *incoheres* more with *unacceptable* beliefs. (In ECHO, a proposition's acceptability is reflected by its activation value: from -1, full rejection, to +1, full acceptance.) (8) The overall coherence of a network of propositions depends on the local pairwise cohering of its propositions.

As mentioned above, we and others have shown specific (and generally diagnostic) empirical support for all of the basic principles, save competition. (E.g., in contrast to suggestions that hypotheses dominate evidential propositions, Schank & Ranney, 1991, found that subjects generally afford data priority to the evidence they consider.) The recently proposed competition principle (6; cf. Thagard, 1992, etc.) has not yet been rigorously tested. In many ways, it seems plausible: Suppose one hears that an evil dictator was dead due to a stabbing; then one later hears that he was dead due to gunshots. We might assume that the reports offer competing hypotheses (stabbing vs. shooting) for a datum (death). Of course, they *might* be cohypotheses, hence covered by principle 2; but without an offered explanatory relationship (e.g., "the dictator died of concurrent blood loss from both gunshot and stabbing wounds"), we are probably justified in assuming—by default—that the two propositions incohere.

The ECHO Model and Its Variants

The ECHO implementation of TEC uses a connectionist architecture in which each node/unit represents a proposition. The algorithm itself is fairly simple. (Of course, one theorist's "elegant, parsimonious" model may be another's "simplistic" model; see contributions to Giere, 1992.) We provide here a precis of ECHO, as much explication of the basic algorithm and its program(s) are presented elsewhere (e.g., Thagard, 1989 & 1992, Schank & Ranney, 1991, and Ranney & Thagard, 1988): ECHO evaluates beliefs (i.e., nodes, such as hypotheses and evidence) by satisfying the many constraints that result from the explanatory relations presented to the system (in accord with a few numerical parameters). In the present paper, ECHO's nodes and links (i.e., beliefs and explanatory/contradictory relations) are primarily either saliently provided in stimulus materials (Study 1) or essentially generated by subjects themselves (Study 2). Given declared input propositions and relations among them, node activations are updated with a standard relaxation technique.

To distinguish the variant of ECHO that does *not* use the competition principle from the one that does, we refer (historically) to them as ECHO1 and ECHO2. ECHO2's extra principle is implemented by searching an input network representation for propositions that independently (i.e., not *jointly*, as in principle 2) explain a third proposition. Such propositions, e.g., "(dictator was shot)" and "(dictator was stabbed)," are marked as competing, and an inhibitory link (a competitive, incohering, relation) is inferred and set up between the two in the computer representation. This link functions like a contradiction (as in principle 5), suggesting that the two hypotheses are probably mutually exclusive.

Our Empirical Goals

The present experiments are analyzed with a threefold mission. First, we test the competition principle's utility. If one hypothesizes that the principle helps describe human reasoning, then ECHO2 should model subjects' data (here, believability ratings) better than ECHO1. Alternatively, if people do not engage in much competitive inferencing, or if the principle is lacking, then the correlation between behavioral data and ECHO2's activations would be no more (and possibly less) than the fit offered by ECHO1's simulations.

Our second goal is to better understand the dynamics of human belief revision as problems become more complicated. Again, alternative hypotheses appear: If one presumes that people usually become more globally coherent as they reason more fully about a problem, one would expect increasing correlations, over time, between ECHO and subjects' assessments of considered beliefs. In contrast, one might assume that people are often overwhelmed by increasingly complex problems, so the coherence of their thinking drops with successively richer sets of information (i.e., with constant chunking/expertise/familiarity levels); this alternative is suggested by Ranney's (e.g., in press-a) theory of local coherence, in which a "spotlight" of explanatory coherence has a limited beamwidth (only) within which one remains conceptually coherent. Self-contradictory and inconsistent behavior observed in the informal physics domain (e.g., Ranney, in press-b), and general arguments for the adaptiveness of such processing limits (Ranney, in press-a), support this view.

Finally, we intend these experiments to offer a more informed foundation for using ECHO prescriptively, as part of an environment to help students better structure and evaluate their arguments. The following experiments each address our three goals, using considerably divergent methods that provide critically important contrasting perspectives.

Study 1

This experiment involves simulations of evaluations of a successively richer problem situation. The method is similar to part of Schank and Ranney's (1991; the "dynamic modeling" part), in which a more and more elaborate (largely textual) situation is segmented by requests for believability ratings for each of the problem's propositions. In contrast to those in the 1991 study, we presently employed a more realistic and complex reasoning domain. We also expected the problem to yield the sort of conceptual Gestalt restructuring elicited in past work (e.g., Ranney, 1987/1988, 1988, & in press; Ranney & Thagard, 1988; Schank & Ranney, 1991).

Method

Subjects and Materials. We presented 30 University of California undergraduate volunteers with a problem relating to Berlin's location relative to the border that (until recently) divided Germany. The reader is advised to skim the Appendix, which shows the (annotated) problem materials, divided into five temporal segments. Also shown are the textually embedded propositions (e.g., {WG1} = "Berlin was located entirely in West Germany"), (underlined) explanatory relations, and (*italicized*) contradictory relations. (A graphical Berlin problem, first designed and assessed by Boaz Keysar (1990), was modified by Ranney (in press-a) before its current version.)

Procedure. As in Schank and Ranney (1991), after each time segment, subjects rated the believability of each proposition read so far. Each segment's text held both prior and new text (new in boldface). Ratings used a 1-9 scale (Schank & Ranney, 1992), with 1 = "completely unbelievable" and 9 = "completely believable." Subjects could not review prior segments' ratings, but could re-read the current text. When isolated for rating, the last two propositions were stated as (E8:) "The map of East and West Germany, prior to my drawing in the border, was accurate," and (H1:) "The border that I drew between East and West Germany is accurate."

Results and Discussion

Subjects' Believability Ratings. The materials yielded Gestalt reorganizations for students who did *not* seem to know Berlin's location *a priori.* The 17 subjects who first rated belief EG1 as "7" or less (mean = 3.2) are termed "naive," and the remaining ("knowledgeable") 13 seemed to *know* Berlin's location. (Subjects' drawn—and explained—borders largely supported these categorizations.) Table 1 shows mean ratings for the problem's 17 propositions, broken down by prior geographical knowledge. Note the "believability trajectories" for basic notions about Berlin's location: OB1 ("On the Border"), EG1 ("in East Germany"), WG1 ("in West Germany"), and NOB ("Not On the Border"). Naive subjects clearly initially preferred the incorrect "straddling" (OB1) hypothesis to the other three. At Time 4, though, OB1, EG1, and NOB are nearly equivalent. After Time 5, OB1 is moderately rejected, while the East German placement of Berlin (EG1; and NOB's denial of OB1) is moderately accepted. By then, at most five of the 17 naive subjects favored OB1 in either their border-drawings or ratings.[1] In contrast to these subjects, Table 1 shows that knowledgeable subjects generally highly preferred

[1] E.g., two subjects held that the border formed a ">" angle deeply toward the East—yielding only a "2/3-pie"-like East Germany—so Berlin could still be (a) divided and (b) on the border "at the corner/vertex." In contrast, many naive subjects explained/wrote that Berlin was too far East to be on any reasonably placed border. Three others gave self-contradictory drawings and ratings (cf. Ranney, 1987/1988, 1988, & in press-b).

the EG1 and NOB hypotheses throughout. (Even so, one such subject's ratings were odd and inconsistent, e.g., with respect to his drawing, especially at Times 4 and 5.)

Table 1. Mean believability ratings for subjects who did/did-not know the location of Berlin *a priori*.

Prop	Time 1	Time 2	Time 3	Time 4	Time 5
OB1	2.4/6.1	2.0/5.7	1.8/5.6	1.8/4.9	1.4/4.0
OB2	2.2/6.6	2.0/5.3	1.8/4.9	1.7/4.1	1.9/3.3
OB3	2.9/7.4	2.8/6.6	3.5/6.4	4.4/6.1	3.1/4.6
EG1	8.9/3.2	8.9/3.8	9.0/3.9	8.3/4.9	8.5/6.5
EG2	7.4/3.5	8.0/4.3	7.8/5.2	7.8/5.1	8.3/6.7
WG1	2.2/2.6	1.7/2.8	1.6/2.2	1.6/2.1	1.1/1.4
WG2	5.8/6.4	5.8/7.0	5.9/6.8	6.0/6.9	5.2/6.3
NOB	7.8/3.3	8.2/4.9	8.5/4.4	8.5/5.3	8.5/7.1
E1	8.2/8.0	8.9/8.5	9.0/8.5	9.0/8.4	9.0/8.1
E2	8.2/7.8	7.9/6.8	8.3/6.9	8.4/6.1	7.9/5.8
E3	8.4/7.8	8.4/7.8	9.0/8.0	9.0/7.4	9.0/6.6
E4	----	9.0/8.5	9.0/8.4	8.8/8.1	9.0/7.8
E5	----	----	8.4/8.4	8.4/8.4	8.4/8.2
E6	----	----	8.2/8.3	7.9/7.9	8.2/8.2
E7	----	----	----	8.4/7.8	8.8/7.9
E8	----	----	----	----	8.4/7.7
H1	----	----	----	----	6.5/5.6

Table 2. ECHO1, ECHO2 activations for Berlin encoding.

Prop	Time 1	Time 2	Time 3	Time 4	Time 5
OB1	.80,.82	.80,.80	.78,.82	.71,.82	.68,.82
OB2	.58,.42	.54,-.17	-.24,.47	-.45,.46	-.47,.45
OB3	.52,.53	.52,.53	.52,.53	.50,.53	.49,.53
EG1	-.66,-.54	-.64,-.30	-.38,-.56	.29,-.47	.48,-.39
EG2	-.57,-.47	-.47,.28	.36,-.59	.58,-.57	.61,-.56
WG1	-.12,-.58	-.17,-.67	-.53,-.57	-.68,-.59	-.70,-.60
WG2	-.23,-.33	-.24,-.34	-.30,-.32	-.31,-.33	-.30,-.33
NOB	-.65,-.64	-.65,-.62	-.64,-.64	-.55,-.63	-.50,-.62
E1	.66,.62	.66,.62	.66,.62	.66,.62	.65,.62
E2	.66,.62	.66,.62	.66,.62	.66,.62	.65,.62
E3	.64,.59	.64,.59	.64,.59	.64,.59	.64,.59
E4	----	.51,.55	.68,.53	.70,.53	.70,.53
E5	----	----	.66,.61	.66,.61	.66,.61
E6	----	----	.70,.72	.71,.72	.71,.72
E7	----	----	----	.61,.31	.63,.41
E8	----	----	----	----	.62,.47
H1	----	----	----	----	.28,.05

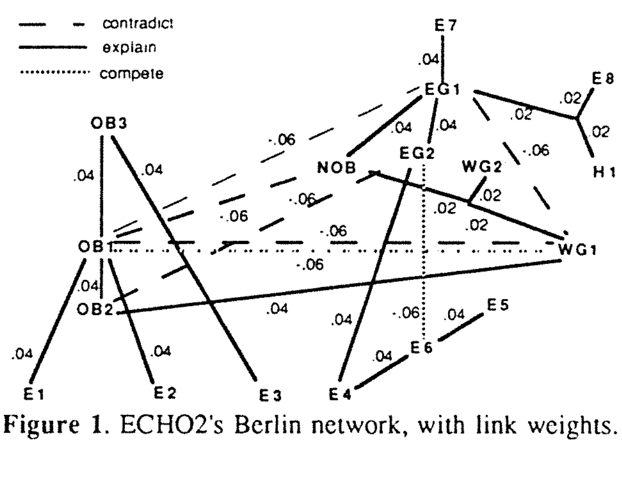

Figure 1. ECHO2's Berlin network, with link weights.

ECHOs' Simulations/Predictions. Figure 1 offers a network representation (cf. Ranney & Thagard, 1988) of the information from the problem's materials for ECHO2 (i.e., with competition). (Beliefs that are above in the figure explain those below.) Only evidential propositions (E1 - E8) were afforded data priority. Joint explanations (e.g., {NOB, WG2} explaining WG1) are indicated by lines that converge before reaching an explanandum. The link weights (and other parameters) were standard, for both the pictured ECHO2 and (not pictured) ECHO1 representation (Ranney & Thagard, 1988; Schank & Ranney, 1991 & 1992; Thagard, 1992).

While also differing in (standard) parameter settings, ECHO1's representation employed neither of the two competitive links shown in Figure 1 for ECHO2's representation. However, as the competition principle has been explicated and incarnated in ECHO2 (Thagard, 1992), neither of the links seem appropriate—although properly implemented vis-a-vis the problem's materials. For instance, in the text, OB1 and WG1 explicitly contradict; yet since both explain OB2, the new principle—as currently manifested—effectively duplicates the (explicit) inhibitory, contradictory, link with a competitive link with the same (e.g., -.06) weight. The competitive link between E6 and EG2 also appears inappropriate; semantically, E6 and EG2 don't really compete: Why should the registries of planes allowed to land in Berlin compete with the notion that West Germany and West Berlin are not adjacent? While one would not necessarily refer to them logically as cohypotheses, in some respects, the two propositions are part of a larger complex/theory of mutually supportive propositions. Some of the inappropriateness lies in the differing *roles* the propositions play: EG2 (nonadjacency) explains *why* E4 (the Berlin airlift) was necessary, while E6 (airplanes) explains *how* E4 could come about. This semantic subtlety[2] is not an artifact of the direction of explanation; if the EG2-E4 relation is reversed such that E4 explains EG2, then E4 and EG1 would be considered as competitors (since they are hardly cohypotheses), making even less sense.[3]

The activations yielded by both variants (Table 2; for the 17 propositions and 5 times) bear out these difficulties for the competition principle: We lack the space to describe many of the subtleties in the simulations' dynamics; still, note that ECHO1's activations generally follow the temporal pattern of reduced evaluations of both the "border theory" (of Berlin's placement; e.g., OB1, OB2, and OB3) and the "West Germany theory" (e.g., WG1 and WG2), yet increased evaluations of the correct "East Germany theory" (e.g., EG1 and EG2). In contrast, the ECHO2 simulation barely changes its general evaluations of the three "theories."

How Well Do the Simulations Fit? Given the differential *activation* predictions from the two variants, we expected ECHO1's activations to correlate more highly with naive subjects' belief ratings than would ECHO2's. Table 3

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[2] Cf. Aristotle's doctrine of the "four causes" (e.g., "final cause," etc.) We thank Elijah Millgram for pointing out such similarities.

[3] The competition principle was intended to use only hypotheses as competitors, but Thagard agrees (personal communication) that evidence may plausibly serve such roles. Also, it is ambiguous whether Thagard (1992, etc.) intended that competitive links should duplicate explicit contradictory links.

(left side) shows this ($p < .05$), as it provides believability-activation correlations as a function of time, subjects' knowledgeability, and simulation (i.e., ECHO1 vs. ECHO2). Both variants initially correlate with naive students' ratings well (r's between .53 and .71 for differing texts; p's < .001), but less so as the problem's complexity increases. ECHO2's drop is about twice ECHO1's. The differential drop's cause is fairly clear: Both simulations—as well as the naive subjects—initially prefer the "border theory," however, as subjects usually eventually prefer the "East Germany theory," they are better modeled by ECHO1's movement in that direction.

The correlations between knowledgeable subjects' ratings and the variants' activations support this account. One would expect such correlations to initially be low, if not negative, then rise as the text information (and thus a proper simulation) more closely reflects these subjects' *a priori* knowledge. This is indeed observed for ECHO1's modeling, but ECHO2's (with its competition principle) stays around a zero correlation throughout. Naturally, modeling these 13 subjects with EG1 as a datum yields much higher r's—rising to (ECHO1) .732 and (ECHO2) .502 (by Time 5; $p < .001$).

Some Lingering Questions. Both in pattern and overall ($p < .001$), ECHO1 modeled subjects' belief evaluations better than did its competition-principled counterpart, ECHO2. But perhaps this experiment represented an unfair test of the principle, given that only two (rather problematic) competitive links were simulated from the Berlin text. A more representative sample of competitive links might show their relative (if imperfect) descriptive power. The next study addresses this, as well as the following: For naive subjects, does ECHO1 necessarily lose descriptive power with increasingly complex reasoning (e.g., as ECHO1's modeling of this study's subjects dropped over time)? Would this mean that naive subjects reason less normatively (or less "rationally" or in a less "globally coherent" fashion) with increased complexity? If the latter possibility were the case, is it due to a homogeneous processing limitation, or processing biased toward recent information? A recency bias would explain why naive subjects showed more Gestalt-like belief revisions (e.g., for NOB) than predicted even by ECHO1.

Study 2

An extended and more temporal analysis of Schank and Ranney's experiment (1992) further illuminates the above issues, by providing the opportunity for many more competitive links. This is due to its novel methodology, employing what we now term the "bifurcation/bootstrapping method" (see Figure 2). Schank and Ranney developed this method with a pendular release task (from Ranney, 1987/1988, etc.). (The method is general in that, e.g., one could apply it as readily to probability networks as to ECHO networks.) In this method, rather than responding to a largely textual problem and primarily rating propositions provided therein, students generate their own arguments and provide believability ratings for the propositions they (largely) personally generate while ruminating. In this case, students were asked to predict (draw and explain) the trajectory of a pendulum-bob released at the endpoint of an animated pendulum swing. They were then shown, serially, five alternative, commonly predicted, paths (e.g., generated by subjects in Ranney, 1987/1988), and asked to explain why each path may or may not be correct. As a subject reasoned out loud, the interviewer recorded each assertion. After every reasoning segment, the subject rated his/her belief in each assertion and each alternate path. Their verbal protocols were then "sanitized" of evaluative elements (e.g., believability ratings and comments), coded by "blind" ECHO encoders (i.e., unaware of the subjects' ratings), and then simulated in order to correlate the argument-based activations with the sequestered "objective" evaluative ratings.

Table 3. Believability-activation correlations (for N Berlin beliefs) for knowledge levels, times, and model variants.

	Naive			Knowledgeable		
Time	N	ECHO1	ECHO2	N	ECHO1	ECHO2
1	187	.604[a]	.630[a]	143	-.240[a]	-.136
2	204	.394[a]	.403[a]	156	-.193[a]	.126
3	238	.506[a]	.468[a]	182	.206[a]	-.017
4	255	.400[a]	.336[a]	195	.389[a]	.028
5	221	.371[a]	.150[a]	221	.444[a]	.050
All	1173	.449[a]	.382[a]	897	.152[a]	.019

[a]significantly different from zero, at p<.02

Table 4. Pendulum r's for models and 7 times (N beliefs include path-predictions & subjects' assertions; $p < .005$ for all).

Time	N	ECHO1	ECHO2
1 (drawn)	95	.285	.352
2 (path 1)	148	.381	.386
3 (path 2)	194	.413	.423
4 (path 3)	230	.457	.465
5 (path 4)	259	.564	.552
6 (path 5)	292	.548	.562
7 (all paths)	297	.537	.465
Overall	1516	.502	.489

Results and Discussion

We extend Schank and Ranney's analyses (1992; also see it for more details of methodology) in several ways:

The ECHOs' Dynamic Modeling. First, the encodings were parsed into seven accumulative segments (Times 1–7), corresponding to periods during which various sets of alternative trajectory predictions were considered and discussed by the subjects. These encodings were then used to run ECHO1 and ECHO2 simulations. (Schank & Ranney's 1992 analysis reported neither the dynamic modeling, nor modeling based upon ECHO2.) Contrary to Study 1's (Berlin) results, and for both ECHO variants, the rating-activation correlations generally show an *improving* fit over time—even though these representations are considerably more complex than those in Study 1 (see Table 4). Both sets of correlations seem to plateau, yet ECHO2's fit almost significantly (p = .11) drops from its peak to be nonsignificantly higher than its original fit (p > .25). Overall, there is no significant difference between the two variants' fits, also in contrast with the prior study's advantage for ECHO1.

Analyzing the Competitive Links. As the simulations suggest that the competition principle may be useful, albeit imperfect, the competitive links that ECHO2 generated were analyzed to discern what portion seemed warranted (un-

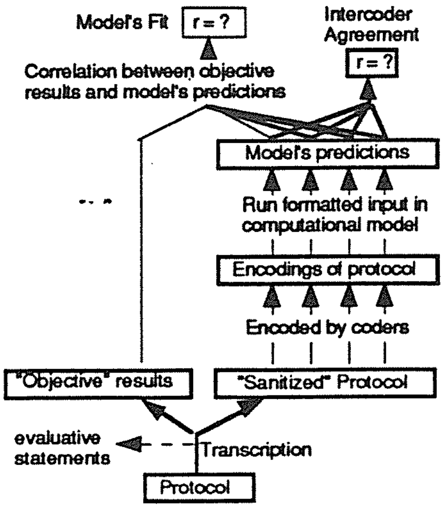
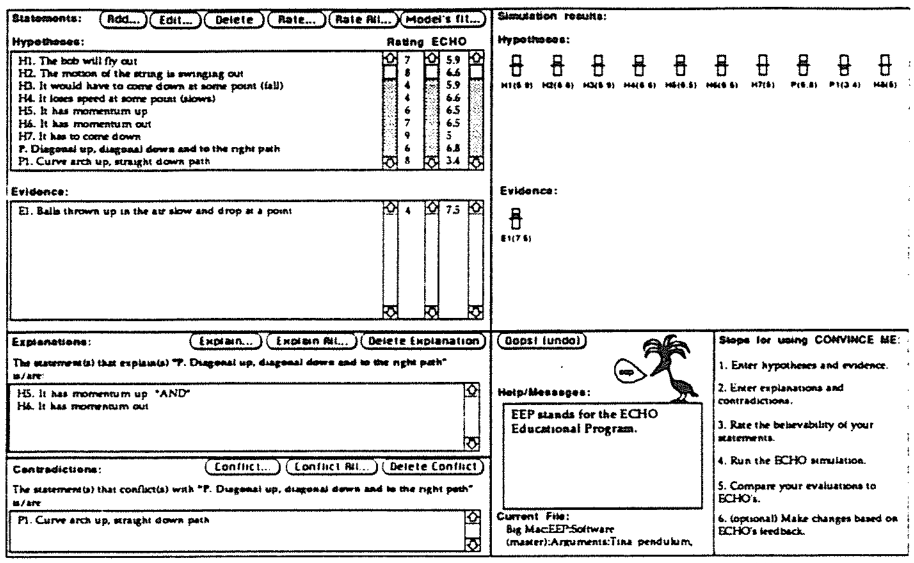


Figure 2. The "bifurcation/bootstrapping method" (Schank & Ranney, 1992).



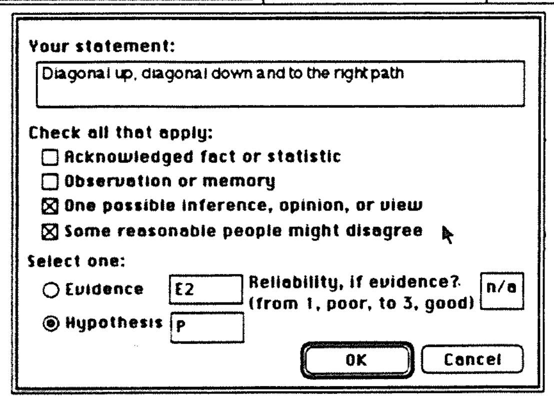


Figure 3. A student adds/edits a belief (bottom) in response to feedback from CONVINCE ME's ECHO model (top).

like the two links in Study 1, which did not). Of the 103 links suited for such analysis, 57% were judged to truly capture an underlying competition. Most of the more nonsensical links were judged thus for the same reason as that for the EG2-E6 link from Study 1: the "competitive" propositions are arguably part of the same theory, albeit sometimes distally related. That the majority of the competitive links seem warranted may explain why ECHO2 fit the data as well as ECHO1 overall (in contrast to Study 1's finding).

Ownership and Familiarity of Reasoning. The increasing fit of the models, over time, may be due to students' "ownership" of these propositions (in contrast to Study 1's propositions). Here, propositions were largely subject-, not experimenter-, provided so they were presumably more familiar—though the reasoning was clearly novel and probably not driven by "naive theories" of motion (Ranney, 1987/1988, in press-b, etc.). Also, ECHO can only model what is encoded; compared to Study 2, students in Study 1 clearly considered more information that we could not encode.

Local Coherence Driven by Recency. One account for the observed increasing correlations would be that, due to an increasing familiarity with the domain, subjects return to and elaborate/explicate earlier arguments. To assess this, we tallied the new explanations and contradictions explicitly mentioned by subjects. The results offer some support for the elaboration/explication notion: The majority (134) of the 246 such links connected old nodes to new nodes. (Still, just two links connected only previously mentioned propositions and 110 *only* connected new nodes.) Other evidence (e.g., from some other of our materials) indicate that the competition principle may also overestimate the basic human processing capacity for incorporating discordant propositions in unfamiliar discourse domains. (We lack space to detail this, but our results agree with many findings in language comprehension.) Moreover, the results above are consistent with the notion of a locally coherent reasoner whose metaphorical spotlight is biased toward lingering on (focusing coherence upon) the most recently generated/recalled regions of a knowledge network (cf. Ranney, in press-a).

Using ECHO to Enhance Students' Reasoning

Based on insights gained from these and past experiments, we developed—and are now assessing—a TEC-based "reasoner's workbench" to help people articulate, structure, and evaluate their theories and arguments (Ranney, in press). The system, CONVINCE ME (Figure 3; Schank & Ranney, 1993), asks students to (1) input their own beliefs (which are relevant to their chosen controversy), (2) epistemically categorize them as hypotheses or evidence, (3) explicate which beliefs explain or contradict/compete with which others, and (4) rate their beliefs' plausibilities. Each student's argument is then simulated, thus predicting which beliefs "should" be accepted or rejected. After contrasting their ratings with the simulation's predictions, students may (a) alter their argument's structure with new belief-additions, -deletions, -explanations or -contradictions, or (b) modify the ECHO model to better suit their individual reasoning style. Thus, CONVINCE ME offers an interpretable and robust interface for explicating arguments and a "reasoning engine" with which one may contrast one's beliefs and revisions. We hypothesize that it will also help people overcome the inherent processing limitations (e.g., unassisted short-term memory) and biases (e.g., recency effects and locally coherent reasoning) that we have observed.

Conclusions

Both studies indicate that TEC's competition principle needs further revision, as it (overall) adds no predictive ability. Beyond adjustments, such as cutting redundancies between competitive and explicitly contradictory relations, a more sensitive algorithm should ensure that would-be competitive propositions are not just filling different semantic roles in the same theory (cf. Harman, 1989). Since ECHO2 sometimes models subjects as well as ECHO1 (as in Study 2), this suggests a descriptive utility for *some aspects* of the principle. Further, a new principle's *prescriptive* utility (e.g., implemented in our "reasoner's workbench") may even reduce the sorts of local rationality often displayed (here and elsewhere) by fairly naive reasoners during on-line belief revision.

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References

Giere, R.N. (Ed.) (1992). *Cognitive models of science*, Minneapolis: University of Minnesota Press.

Harman, G.H. (1989). Competition for evidential support. *Proceedings of the 11th Annual Cognitive Science Society Conference*, 220-226. Hillsdale, NJ: Erlbaum.

Keysar, B.(1990). *East meets west at the Berlin Wall: Mental maps and the changing world order.* Unpublished data.

Ranney, M. (1988). Changing naive conceptions of motion (Doctoral dissertation, University of Pittsburgh, Learning Research and Development Center, 1987). *Dissertation Abstracts International, 49*, 1975B.

Ranney, M. (1988). *Contradictions and Reorganizations Among Naive Conceptions of Ballistics.* Presented at the annual Psychonomic Society meeting, Chicago.

Ranney, M.(in press). Explorations in explanatory coherence. In E. Bar-On, B. Eylon, and Z. Scherz (Eds.), *Designing intelligent learning environments: From cognitive analysis to computer implementation.* Norwood, NJ: Ablex.

Ranney, M. (in press). Relative consistency and subjects' "theories" in domains such as naive physics: Common research difficulties illustrated by Cooke and Breedin. *Memory & Cognition.*

Ranney, M. & Thagard, P.R. (1988). Explanatory coherence and belief revision in naive physics. *Proceedings of the Tenth Annual Conference of the Cognitive Science Society*, 426-432. Hillsdale, NJ: Erlbaum.

Read, S.J. & Marcus-Newhall, A. (in press). The role of explanatory coherence in the construction of social explanations. *Journal of Personality and Social Psychology.*

Schank, P., & Ranney, M. (1991). An empirical investigation of the psychological fidelity of ECHO: Modeling an experimental study of explanatory coherence. *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society*, 892-897. Hillsdale, NJ: Erlbaum.

Schank, P., & Ranney, M. (1992). Assessing explanatory coherence: A new method for integrating verbal data with models of on-line belief revision. *Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society*, 599-604. Hillsdale, NJ: Erlbaum.

Schank, P., & Ranney, M. (1993). Can reasoning be taught? *Educator*, *7*(1), 16-21 [Special issue on Cognitive Science].

Thagard, P.R. (1989). Explanatory coherence. *Behavioral and Brain Sciences, 12*, 435-502.

Thagard, P.R. (1992). *Conceptual Revolutions.* Princeton, NJ: Princeton University Press.

Appendix: The (Annotated) Berlin Problem

[Time 1:] Some people believe that {OB3} the Berlin Wall was part of the long border between communist East Germany and democratic West Germany. That {OB3} would explain why {E3} East Berliners and West Berliners were separated by a wall as well as {OB1} the belief that Berlin was straddling the long border between East Germany and West Germany. This belief {OB1} that Berlin was straddling the long border between East Germany and West Germany explains the belief that {OB2} West Germany and West Berlin were adjacent, how a) {E1} a long border separated East Germany and West Germany, and why b) {E2} East Germans lived in East Berlin while West Germans lived in West Berlin. **[¶]** Others believe that {EG1} Berlin was located entirely within East Germany. That would explain the belief that {EG2} West Germany and West Berlin were not adjacent, and that {NOB} Berlin was not straddling the long border between East and West Germany. The belief that {EG2} West Germany and West Berlin were not adjacent *contradicts* the belief that {OB2} West Germany and West Berlin were adjacent. The belief that {NOB} Berlin was not straddling the long border between East and West Germany *contradicts* the belief that {OB1} Berlin was straddling the long border between East Germany and West Germany. **[¶]** Still others believe that {WG1} Berlin was located entirely within West Germany. This is jointly explained by the assumptions that a) {WG2} the USSR would never allow a Western listening post on communist soil, and b) that {NOB} Berlin was not straddling the long border between East and West Germany. **[¶]** The belief that {WG1} Berlin was located entirely within West Germany also explains the belief that {OB2} West Germany and West Berlin were adjacent. The beliefs that a) {WG1} Berlin was located entirely within West Germany, b) that {EG1} Berlin was located entirely within East Germany, and c) that {OB1} Berlin was straddling the border between East and West Germany all *contradict* each other. **[Time 2:]** {E4} The Berlin airlift brought food, medicine, and other essential supplies into West Berlin during a communist blockade. This {E4} is explained by the belief that {EG2} West Germany and West Berlin were not adjacent. **[Time 3:]** {E5} Toward the end of World War II, it was agreed that Berlin would be divided into American, French, British and Soviet sectors. That {E5} explains why {E6} only airplanes registered from the US, France, Great Britain, and the USSR could fly into Berlin, which in turn explains {E4} how the Berlin airlift brought food, medicine, and other essential supplies into West Berlin during a communist blockade. **[Time 4:]** {E7} Near the end of World War II, the Western forces of the US, France, and Great Britain agreed to halt their troops more than fifty miles west of Berlin, where they met the Soviet troops. This {E7} explains the belief that {EG1} Berlin was located entirely within East Germany. **[Time 5:]** Here is {E8} a map of East and West Germany with the northern and southern points of the border between them marked. (The location of Berlin on the map is accurate.) Join the two points with {H1} a line to illustrate where you believe the border to be. [The map was provided:] How did {E8} the location of the border's southern and northern end-points and {EG1 for most subjects, by this point} the position of Berlin on the map indicate to you where {H1} the border should be drawn, if at all? Please explain.