The Impact of Representation on Coaching Argument Analysis

Violetta Cavalli-Sforza

Center for Biomedical Informatics, University of Pittsburgh
Suite 8084 Forbes Tower, 200 Lothrop Street, Pittsburgh, PA. 15213
violetta@cbmi.upmc.edu

Abstract. Graphical representations have long been associated with more efficient problem solving. More recently, researchers have begun looking at how representation may affect the information that students attend to and what they learn. In this paper we report on a study of how graphical representation may influence interaction between a human coach and a student engaged in analyzing argument texts. We compared coaching interaction with subjects working with a predefined graphical representation to subjects who developed their own representation. The predefined representation, with a better "cognitive fit", to the task, allowed subjects to do more work on their own. Coaching was more systematic and both more efficient and more effective.

1 Introduction

Understanding scientific arguments and scientific controversies is an important aspect of science education even for the non-scientist, and one that has largely been neglected in science school curricula. The Belvedere project, at the University of Pittsburgh's Learning Research and Development Center, sought to develop a computational environment in which students could analyze and construct arguments using a database of short texts drawn from selected scientific debates [1, 2]. Significant attention was devoted to constructing a graphical representation for arguments [3] and research was conducted on the use of coaching strategies to help students generate their own arguments [4, 5]. More recently, Suthers [6] began investigating how representations may bias the information attended to, the knowledge expressed, and the learning outcomes in collaborative critical inquiry.

Using an early version of the Belvedere environment, we examined how choice of graphical representation impacts learning of target argument concepts and coaching interaction between a human coach and learners engaged in an argument analysis task. The graphical representations, experimental design, and overall results of the study are discussed in [7]. Here, after briefly reviewing the design and results of that study, we present a detailed analysis of the impact of representation on coaching and conclude by discussing the relevance of the findings to intelligent tutoring systems.

2 Study Design and General Results

Four subjects, non-science major college undergraduates, participated in an extended experiment in which they studied several concepts pertaining to the description, support and critique of causal theories. They analyzed short texts drawn from a historical scientific debate. They drew diagrams representing the information in the texts, either the description of a causal theory or arguments in support of and/or against such a theory. They received coaching from the experimenter throughout diagram construction.

Two subjects (in the FIXED condition) used a predefined box-and-arrow graphical representation that specifically encoded important concepts of scientific argument. Distinct shapes, enclosing text, represented scientific propositions with different statuses (e.g., rectangle = observation, rounded rectangle = explanation). Links with specific names, directionality, and arrowheads provided different types of relationships between propositions and/or other links. The remaining two subjects (in the FREE condition) had similar graphical primitives available but could use them and label them at will, thereby effectively constructing their own graphical representation. FIXED condition subjects studied sample analyses of texts that used the predefined graphical representation. FREE condition subjects viewed the same analyses through a schematic text-based representation in which sentences were labeled by their role (e.g., "premises", "conclusion", "claim", "grounds", and "warrant").

Subjects in the FIXED condition adapted rather easily to the representation they were given. Subjects in the FREE condition went down very different representational paths. One subject (Free-1) developed, rather laboriously, a representation similar to that used in the FIXED condition, although it remained plagued by inconsistencies and other problems throughout the experiment. The other subject (Free-2) drew the causal theory diagrams using a curious mix of analogical and abstract representation (e.g., using 7 shapes to represent 7 continents). Since the chosen representation could not be easily extended to express more abstract content, for texts containing primarily arguments Free-2 fell back on a labeled text strategy similar to the one used in the instructional materials.

Consonant with Suthers' [6] hypotheses, only subjects who used a box-and-arrow abstract representation (Free-1 and FIXED condition subjects) expressed in their diagrams some of the more complex relational concepts (e.g., multi-step support, dialectical argument patterns), which were realized with distinctive linkage patterns. There was also a link between subjects' use of the concept in the diagram and the ability to give a good definition. The crucial factor underlying these results appeared to be whether the representation used by subjects was *relation-centered*, as box-and-arrow representations are, or *role-centered*, as the labeled-text schema adopted by Free-2 is. These findings point out that it is risky to let students develop their own representation for a task, though it may lead to deeper processing. At best, like Free-1, students will develop a sufficiently expressive representation, but at a significant cost in time, clarity of the resulting work, and attention that could be focused on target instructional concepts. At worst, like Free-2, they may fail to find an adequate representation and consequently may not learn to apply the target concepts.

The second finding of the study, and the focus of this paper, was that a predefined task-appropriate representation, in addition to emphasizing and supporting important instructional concepts, also significantly facilitates coaching. We begin by describing the general coaching approach and the methodology used to code the interaction data for five diagrams, roughly one fourth of the diagrams that subjects drew. We then present results from quantitative and qualitative analyses of coaching, pointing out the key differences between interaction with subjects in the two representation conditions.

3 Coaching Approach

Coaching was provided by the experimenter based on a general mental model of the argument contained in the texts being analyzed. Because there was usually more than one way of representing — and sometimes even interpreting — the content of the text, this approach was deemed more flexible and appropriate than comparing a subject's work to a specific "expert" diagram. For similar reasons, we applied a generally non-interventionist coaching philosophy. The coach waited for the subject to produce at least a partial draft of the analysis before beginning to comment on it, unless the subject appeared to need assistance or specifically requested it. Working from a model was particularly effective with FIXED condition subjects, whose diagrams showed significant overlap with a model that used the same concepts expressed in Belvedere's graphical primitives. With FREE condition subjects, the model had to be even more flexible, in order to allow the coach to map between the subject's representation and the desired analysis and to avoid overly influencing the subject to represent things in a specific way. As a consequence, some of the final FREE condition diagrams deviated more from an ideal analysis than the final diagrams of FIXED condition subjects.

Scaffolding Strategies (SS)	**Coaching Strategies (CS)**
• Remind subject of goal and progress (L)***** • Ask question about a step in the solution (L) • Suggest a high-level solution plan. (M) • Provide a limited number of choices (M) • Give hint(s) about solution path(s) (M) • Suggest crucial step(s) in solution (H) • Perform parts of the solution plan (H) • Lead subject through plan steps by asking questions (H) • Model task for the student (VH)	<u>Positive</u> (+): Praise subject's work (L) <u>Negative</u> (-): Critique subject's work: • Signal potential problem (L) • Suggest information to consider / Signal missing information (M) • Criticize subject's work (tell what's wrong) (H) • Correct subject's work (give right answer) (H) • Explain correction to subject (VH) • Argue with subject (VH)

***** Level of Coach Engagement/Knowledge Required (L – low; M – medium; H – high; VH - very high)

Fig. 1. Summary of scaffolding and coaching strategies

Two classes of strategies were used in providing assistance. Scaffolding strategies were applied when the subject seemed unable to proceed on a task without receiving assistance. Coaching strategies were applied after the subject had produced a (partial) analysis. The strategies employed are shown in Figure 1. The application of scaffolding and coaching strategies was interwoven. For example, a coaching strategy would be used to evaluate the subject's analysis, which would lead the subject to attempt improving the analysis. This would call for a scaffolding strategy to help the subject carry out the improvement. Within the two general classes, individual strategies differ in the amount and type of knowledge required, as well as in the degree of coach engagement in the task. The coach always attempted to begin with low engagement/low knowledge strategies, which require the subject to do more work, and to progress to more demanding strategies only when necessary.

4 Analysis and Coding Methodology

Our approach to analyzing the coaching interaction data overlaps with those developed by Pilkington [8] and Katz *et al.* [9], but reflects the needs of our application. For each diagram, the raw protocol of the interaction (transcribed from videotapes and indexed to the diagrams) was synthesized into an *interaction summary*. First, the protocol was segmented into groups of related utterances by the subject and/or the coach. Each utterance group represents a self-contained thought by one person and abstracts away interruptions and simultaneous speech by the other person that were not extending the original thought in a significant way. The utterance group was then summarized into a *summary utterance*, a single statement that reflects the essential content of the utterance group. One or two summary utterances, taken together, form one *interaction unit*. An interaction unit can include:

- a summary utterance by the subject and one that represents the coach's response
- a summary utterance by the coach with a verbal response or action by the subject
- a summary utterance by the coach alone, for example a comment praising the subject's work.

An example of an interaction unit composed of two summary utterances corresponding to the protocol excerpt in Figure 2 is the following:

S: I'll use an *and* to show the relation between items 1, 2, 3.
C: You should be more specific than *and*. It has to do with time sequence.

S: Okay huh (thinks) Okay now I wanna say that this *(points to shapes 1, 2, and 3)* broke up, do I just well okay I guess I'll just do another *and*.
C: The fact that the c- the big c- supercontinent broke up **S:** Hm hm
C: Right and how to link it to the previous one? **S:** Hm hm
C: Huh is there huh there is yeah there can be an 'and' relationship and I think in this case there can be something a little more specific huh that has to do with the with the time sequence in which the two events happened in which the time relative to…*(subject interrupts)*

Fig. 2. Protocol fragment corresponding to an interaction unit

The summary utterance for the coach abstracts away the two intermediate utterances by the coach, which are only making sure that the coach knows what the subject is referring to. Although the subject is speaking in terms of graphical links (e.g. *and*), the coach is hinting that simple conjunction is not the correct relationship among the statements..

Several interaction units may be grouped into a single interaction group to indicate that they all pertain to a specific issue or topic of discussion. Interaction groups may be nested to show the overall structure of the interaction. The top-level group has a heading describing the main topic of the interaction, with nested interaction group headings giving the various subtopics addressed.

Each interaction unit was also classified on the basis of the primary *content* as well as the communicative *form* of the interaction. The content categories include: rhetorical structure (**Cs**), representation (**Cr**), scientific domain (**Cd**), graphical interface (**Cg**), and meta-topics (C**m**, mostly concerning general ways of carrying out a task). An interaction unit dealing primarily with the interrelationship of two statements in the domain text was coded as rhetorical structure; an interaction unit dealing primarily with the appropriate link, link name, or linkage pattern to use to represent that relationship in the graph was coded as representation. For example, the interaction unit corresponding to Figure 2 was analyzed as having content "rhetorical structure" and form "hint". The communicative form categories represent different communicative actions used by the coach to help the subject improve his or her graphical analysis of a text. A partial list of categories used is shown in Figure 3.

Fd: remind of prior action	**Fq**: ask question
Fe: explain why	**Fr**: review (progress, definition, etc.)
Fh: hint at characteristics of answer	**Fs**: suggest what, how
Fi: draw attention to	**Ft**: tell what, how
Fn: criticize by saying no/bad/wrong	**Fv**: verify what subject /diagram means
Fp: praising, agreeing	**Q**: question (information seeking, not coaching)

Fig. 3. Coding of Communicative Form of Interaction

5 Quantitative Analysis of Coaching Interaction

The goal of the quantitative analysis of coaching interaction was to characterize differences in the content and form of coaching interventions required by subjects in the two experimental conditions. Differences were noted in both the content and the communicative form of the interaction.

5.1 Content of the Interaction

Table 1 shows the distribution of interaction units over content categories. For each subject, the first row gives the absolute number of interaction units in each category. In the second row, in *italics*, the TOTAL column shows the partial total of interaction units over the three most salient categories: rhetorical structure, representation, and domain. The remaining columns show the percentage of interaction units in each of the three categories with respect to this partial total. There is significant variation among subjects in the number and proportion of interaction units.

Table 1. Distribution of Interaction Units Over Content Types

Subject	Structure	Representation	Domain	Belvedere	Meta	TOTAL
Free-1	81 *57.0%*	47 *33.1%*	14 *9.9%*	18 —	6 —	**166** *142*
Free-2	101 *79.5%*	24 *18.9%*	2 *1.6%*	17 —	15 —	**159** *127*
Fixed-1	66 *77.6%*	11 *12.9%*	8 *9.4%*	17 —	7 —	**109** **85**
Fixed-2	83 81.4%	17 *16.7%*	2 *1.9%*	24 —	1 —	**127** **102**
TOTAL	**331** *72.6%*	**99** *21.7%*	**26** *5.7%*	**76** **—**	**29** **—**	**561** **456**

The proportion of interaction units for rhetorical structure is similar for all subjects except Free-1, for whom it is lowest, since it competes with other content categories and especially representation. The proportion of interaction units concerned with representation is higher for subjects in the FREE condition than subjects in the FIXED condition. In particular, the number of interaction units is significantly above expected for Free-1, who was actively developing a graphical representation, and below expected for Fixed-1 who, with few exceptions, adapted well to the use of the FIXED representation conventions. Free-2 also has a sizeable proportion of interaction units on the topic of representation, although given the total number of interaction units it is actually below expected value. The results for this subject are skewed by the large number of interaction for one diagram, which account for about one third of the total interaction units, are mostly in the rhetorical structure category, and are caused by an unsuccessful coaching interaction. If that diagram is disregarded, the percentage of interaction units on representation climbs to 32.9% of interactions (23 interactions) in the three main categories.

5.2 Form of the Interaction

Table 2 gives a summary of the interaction units for each subject grouped by form of communicative action and content. The numbers are not large, but this data suggests a number of differences across subjects and conditions.

Subjects in the FREE condition were asked many more questions by the coach (category **Fq**) in the course of coaching, in order to elicit from them the relationships in the rhetorical structure of the text they were trying to represent. Questions in this category were usually related to the implementation of one of the scaffolding strategies. In addition, the coach needed to ask Free-2 a number of questions in order to understand what the diagrams meant (**Q**). Subjects in the FREE condition were also told what to do (**Ft**) more often than subjects in the FIXED condition, who received suggestions (**Fs**) more often. Both are examples of scaffolding strategies. Subjects in the FREE condition received more reminders (**Fd**) about their previous work, mostly regarding the use of the representation. Reminders implemented both coaching (criticizing) and scaffolding (hinting) strategies.

Table 2. Interaction Unit By Subject, Content and Communicative Action

Encoding	Fr-1			Fr-2			Fx-1			Fx-2			Tot
	Cs	**Cr**	**Cd**	**Cs**	**Cr**	**Cd**	**Cs**	**Cr**	**Cd**	**Cs**	**Cr**	**Cd**	
Fd	**1**	**4**			**1**								6
Fe	3	6		*6*	7		3	3		***9***		1	38
Fh	2	1		***6***			3		1	***7***	1		21
Fi	**8**	5	2	4			**6**	1	2	**8**	1		37
Fr	3			**9**			1			2			15
Fq	**22**	2	5	**23**	2		7			10	1		72
Fs	4	9	1	3			**4**	1		**7**	4		33
Ft	**7**	4		**9**	2	1	3	1	1	1	2		31
Fv	2			6	4		**7**			**9**			28
Q	3	3		**10**	5		4		1	4			30
Tot	81	47	14	101	24	2	66	11	8	83	17	2	456

LEGEND: Cs = rhetorical structure, **Cr** = representation, **Cd =** domain

The coach verified (**Fv**, coaching) subjects' intentions more often in the FIXED condition, asking the subjects if what they drew was really what they meant and signaling, in a non-directive low-engagement way, that there was a problem with the diagram. A similarly low-engagement way of signaling a problem was just to draw attention to a point in the diagram (**Fi**, coaching). It was often sufficient to get the subject to correct the problem, and was used more frequently and successfully with subjects who had drawn detailed diagrams (Free-1, Fixed-1, and Fixed-2).

The general picture painted by Tables 1 and 2 is that the FIXED representation required less interaction, allowed subject and coach to focus on rhetorical structure, and resulted in more coaching of subject work and less scaffolding to get the work done. Both scaffolding and coaching strategies used with subjects in the FIXED condition were less directive and required lower coach engagement. This conclusion was supported by a qualitative analysis of the coaching interaction.

6 Qualitative Analysis of Coaching Interaction

In addition to the detailed quantitative analysis of coaching actions described above, we examined more qualitatively the interaction over a larger number of diagrams and compared the characteristics of the interaction between subjects in the same experimental condition and between experimental conditions.

6.1 Coaching in the FIXED Condition

Although not all the final diagrams for subjects in the FIXED representation condition were error-free, the diagrams were mostly quite good. The fault for lingering imperfections rested with the coach who either forgot to or chose not to pursue problems further. One feature of the coaching interaction that was striking and common to FIXED subjects was the overall efficiency of the communication, especially when compared to the interaction with Free-1. In all but one instance for each subject, diagrams had only very localized problems, requiring changes to individual elements of the diagram and little coaching. The coach could usually just point out that there was a problem, or indicate the general nature of the problem (is that shape right, should the link start there?), and the subject could fix the problem quickly, often without further help. In some cases, subjects found the problem on their own simply by reading over the diagram. If further coaching was needed, it mostly required hinting.

The interaction with Fixed-1 was very synthetic and to the point. Coaching tended to be very non-directive, hinting at the existence and nature of a problem but leaving most of the changes up to the subject. Fixed-2 was a little more hesitant and exhibited more trouble with applying some of the instructional concepts. However, although the interaction with this subject was somewhat longer, it was characterized by the same overall efficiency and effectiveness.

6.2 Coaching in the FREE Condition

Subjects in the FREE condition differed from each other as much as, if not more than, they differed from Fixed-1 and Fixed-2. They were, however, similar in that they both required significant interaction to clarify the representation they were developing. Unstable and insufficiently expressive representations made coaching more difficult and not always effective.

For Free-1, the coaching interaction was less clearly separable into short distinct episodes and mostly occurred during construction of the initial diagram. Although Free-1, like the FIXED condition subjects, used a box-and-arrow type of representation, many of the links did not correspond to FIXED representation links (especially in causal theory diagrams), nor were shapes used in the same way. This subject was not always explicit or consistent in his use of the representation, so the coach could not always evaluate and correct the diagrams by referring to a canonical model. Free-1 encountered substantial difficulties in choosing the level of representation (choosing the primary objects to represent as shapes), especially in diagramming causal theories, and appeared to be resistant to coaching. On several occasions, when the coach was trying to explain or suggest something, Free-1 interrupted to propose one or more alternative solutions, disregarded interventions from the coach or insisted on a particular way of doing things, and read the diagram over and over to check the representation. As a result, the coaching process was less effective, the protocols were very extensive, and each diagram took a relatively long time to construct. Protracted interactions were, at times, extremely frustrating for the coach, although the subject did seem to genuinely enjoy the task.

Free-2 mixed direct and abstract representations in diagrams describing a causal theory. In these diagrams, interaction often concerned representation and was necessary in order for the coach to understand the representation and verify that the diagram correctly represented the content of the text. In diagrams of texts containing primarily arguments, Free-2 stopped using box-and-arrow graphics altogether and coaching addressed rhetorical structure almost exclusively. With two notable exceptions, coaching interactions with Free-2 tended to be brief; this was due, in large part, to the low level of detail in this subject's analysis of texts. Free-2's diagrams were very synthetic relative to the ones drawn by other subjects. The coach attempted to induce this subject to show information at a greater level of detail, especially information that showed the relationship of different texts and portions of texts to each other. In some cases, however, Free-2 had difficulty diagramming rhetorical relationships due to the limitations of the representation.

FREE condition subjects ran into serious problems only at a few points in the construction of their diagrams. However, unlike for FIXED condition subjects, coaching was not always successful. For Free-1, a coaching failure occurred while trying to develop a representation for describing causal theories; for Free-2, coaching failed catastrophically when this subject was unable to capture the argument structure of a text by applying and extending the representation.

7 Summary and Conclusions

In the last few years computational environments for teaching argumentation and critical inquiry skills have been developed (e.g., [3, 10, 11]). In some of these environments, the argument is represented in an external artifact, using a graph or some other type of representational scheme (e.g., containers, matrix). Suthers [6] hypothesizes that these external abstractions provide: 1) cognitive support, by helping learners "see", internalize, and keep track of complex relations; 2) collaborative support, by providing shared objects of perception that coordinate group work by serving as referential objects and status reminders; and 3) evaluative support for mentors, by giving a basis for assessing learners' understanding of scientific inquiry, as well as of subject matter. He further proposes that representation may bias the information attended to, the knowledge expressed, and learning outcomes.

In this paper, we have presented some findings concerning the impact of representation choice on coaching argument analysis. Our findings support Suthers' hypotheses. Representations with a good "cognitive fit" for the task provide cognitive support, resulting in analyses of arguments that apply instructional concepts, are clearer and more correct, and express information at the right level of detail for the task. They provide collaborative and evaluative support, even when the collaborators are a learner and a coach, by supporting a more efficient and effective coaching interaction, allowing the learner to do more of the work and requiring less engagement from the coach. Such representations are also not easy to develop, and the deeper understanding that learners may gain by trying to develop a suitable representation is likely to be offset by the increased difficulty in communicating with another agent, be it another learner or a coach, a human being or a machine.

These findings are important for computer-assisted coaching of argumentation, since the capabilities of automated coaches, especially in complex and hard-to-formalize domains, are still well behind those of a human coach. Even an automated coach, with limited domain knowledge but with a good knowledge of argument and communicating with a learner through an adequately expressive and mutually well-understood representation, has some chance of providing useful advice. In contrast, a computer coach that shares with a learner a poorly understood or inadequate representation, be it natural language or a diagrammatic representation, is even less likely than a human coach to achieve a successful coaching interaction.

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