Discourse Processing in Situated Cognition: Learning through Tutorial Dialogue in Complex Domains

Carl H. Frederiksen, Marguerite Roy, and Denis Bédard[1]
Laboratory of Applied Cognitive Science
McGill University
Montreal, Quebec, Canada H3A 1Y2
ed76@musica.mcgill.ca

Abstract

This study set out to apply a model of situated discourse to analyze tutorial dialogue in a complex well-defined domain of problem solving in engineering. One tutor met individually with three students to teach them to solve shear force and bending moments problems. The participants' discourse and actions were analyzed according to a situated discourse model. Quantitative analyses of the tutorial dialogue affirmed that the constraints on situated discourse processing identified in the model predicted the propositional content and conversational functions of utterances produced by both the tutor and the students. Qualitative analysis of the conceptual content of the tutor's dialogue for Problem 1 revealed several distinct types of situation models that constituted the meaning associated with the situated discourse and action. The students initially (Problem 1) received this information, their participation consisting mostly of observing, and participating in low-level algebraic procedures with tutorial guidance. Students' problem solving and dialogue on subsequent problems (2 and 3) displayed their ability to solve problems with some tutorial assistance. These results demonstrate that analysis of tutorial dialogue from the standpoint of cognitive models of discourse processing can provide detailed information about the conceptual situation models involved, and the cognitive processes used by the participants.

Introduction

There has been growing acceptance of a constructivist view of learning (i.e., learning as situated cognition) in which contextual and social processes support shared cognition and learning in natural situations or domains of knowledge and activity (Resnick, Levine, & Teasley, 1991). This view has been used to advocate particular models of instruction such as cognitive apprenticeship (Brown, Collins & Duguid, 1989), and has prompted theoretical debate over the relationship of conceptual knowledge, symbolic information processing, and learning, to the social and situational contexts in which they occur (Vera & Simon, 1993). However, despite the recognition that situations play an important role in shaping cognition, we lack studies that explicitly link characteristics of situations to the cognitive processes and learning outcomes of participants within these situations. Sociolinguistic studies of language use within natural social contexts of learning and instruction have established that conversational discourse plays a central role in facilitating cooperative activity and learning within natural learning situations. In addition to its social functions as a medium for interaction, communication, and cooperation, conversational discourse is also a principal medium through which students' acquire new knowledge and learn to apply their knowledge in practical situations of cognitive activity (Lemke, 1990). In addition, recent studies have investigated how discourse interaction in instructional situations supports students' knowledge construction and development of competence in particular, well-defined subject-matter domains in mathematics and science (Fox, 1993; Greeno, 1991; Leinhardt, 1993; Schoenfeld, Smith, & Arcavi, 1993). However, despite the recognition that situations and language play key roles in shaping knowledge, cognition, and learning, few studies have attempted to systematically examine the cognitive processes and representations that underlie discourse interaction and learning from natural-language discourse in authentic instructional situations. Studies of the cognitive processes involved in learning through conversational discourse, therefore, ought to lead to more precise models of the processes involved in situated learning and cognition.

In the present study, existing models of the cognitive representation and processing of text and discourse were applied to study the cognitive processes and representations involved in discourse interaction within a complex instructional situation and domain (Frederiksen, 1986; Frederiksen & Breuleux, 1990; Frederiksen & Donin, 1991; van Dijk & Kintsch, 1983). A "situated discourse model" was developed to extend current discourse processing theory to model discourse interaction (i.e., tutorial dialogue) within a specific tutorial situation in a well-defined, knowledge-rich domain of problem solving in engineering. This model identified specific classes of constraints on tutorial dialogue which were tested in the present study. The model also provided a theoretical framework for analyzing the conceptual and semantic (propositional) content and conversational structure of the tutor's and the students' discourse interaction and their relationship to concurrent problem-solving behavior. Using cognitive models of discourse analysis, we studied the conceptual "situation models" (i.e., propositional structures, conceptual networks, and procedure frame representations) that the tutor and students displayed through their conversational discourse over the course of a tutoring session. By analyzing the characteris-

[1]Now at Université de Sherbrooke, Département d'éducation spécialisée, Sherbrooke, QC, Canada, J1K 2R1.

tics of these representations, we were able to investigate how situation models define and make public the knowledge that students need to become proficient in the domain, how situation models displayed through tutorial dialogue within a problem-solving context support students' comprehension and learning, and how the tutor used the conversational interaction to support students' problem-solving and reasoning.

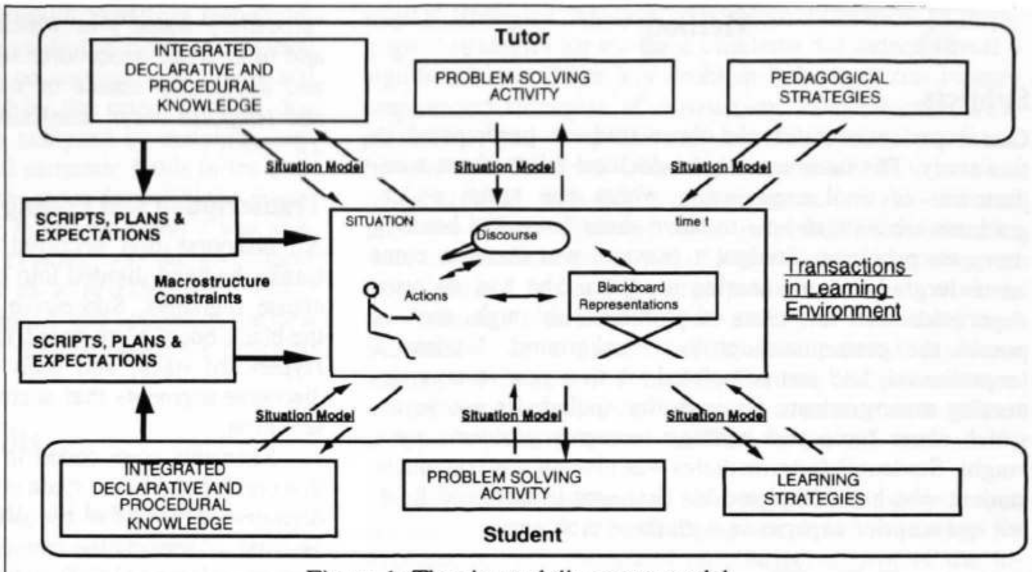

Figure 1: The situated discourse model.

The Situated Discourse Model

Our analysis of discourse processing within tutorial situations was guided by the *situated discourse model* (Figure 1). Consistent with sociolinguistic research on tutorial dialogue, participants are seen as interacting through discourse which they co-construct through their conversational interaction. This interaction occurs in a "transaction space" that includes the participants' concurrent actions (e.g., in solving the problem) and any external knowledge representations (e.g., diagrams, equations, or graphs written on a "blackboard" workspace). At any time, the tutorial dialogue reflects these actions and external representations, as well as the tutor's and the student's knowledge, their cognitive processes in applying their knowledge to understand and solve problems, and their pedagogical or learning strategies. This entire process is embedded within a social context which structures the tutorial interaction. This includes a participation structure (that reflects each participant's perception of his or her role or identity as a student or tutor and how these perceptions govern participants' relationships to one-another and the nature of their participation in the learning situation); and the social organization of the tutoring situation itself, that is, the norms or expectations participants have about their patterns of social interaction and participation within a tutoring situation. Although we recognize that the social context is an important aspect of any learning situation, the primary focus of the present study was on the question of how situated discourse supports students' learning in a particular subject-matter domain within a tutorial learning situation that is relatively typical of those that occur in science and engineering at the University level.

Our model views the structure of a tutorial dialogue (including its sequential and topical organization and the form, propositional content, and conversational functions of individual utterances) as a reflection of processes of situated *conversational inference* that enable the participants to construct and update conversational frames (Gumperz, 1992; Tannen, 1993), that is, *conceptual situation models* (van Dijk & Kintsch, 1983), on a moment-to-moment basis. Participants' situation models at any point in the tutorial interaction reflect cognitive, situational, and macrostructure constraints. *Cognitive constraints* include the participants' current domain knowledge, their cognitive activities in using their knowledge to perform tasks within the learning situation (e.g., reason or solve problems), and their preferred strategies for learning or tutoring. *Situational constraints* include the local discourse context, and any external representations or overt actions that occur within the learning situation. The situation models that a tutor constructs for a student and displays through his or her discourse and actions define a meaningful context within which the student can construct his or her own situation models, and these provide the basis for learning and transfer to new problem-solving situations. Finally, the conversational discourse reflects *macrostructure constraints* governing the participants' communication and activity within the situation, including scripts or expectations concerning the social organization of the tutoring session, and plans for organizing problem-solving activity and use of subject-matter knowledge topically or sequentially within the interactive learning situation.

This model predicts that the structure of interactive situated discourse will reflect the following constraints: (a) the declarative and procedural knowledge of the tutor and student; (b) concurrent cognitive activity of the tutor and student; (c) pedagogical strategies used by the tutor, and learning strategies used by the student; (d) external representations produced or manipulated in the workspace; macrostructure constraints such as (e) the tutor's script for the session and (f) the tutor's instructional plan ; the discourse microstructure including (g) local patterns of conversational speech acts and (h) local propositional inferences that are based on the content of speakers' prior utterances; and (i) high-level tutoring strategies (e.g., "modeling and explanation", or "coaching and evaluation") that are reflected in particular patterns of local pedagogical strategies. These predictions were tested in the present study.

Method

Subjects

One experienced tutor and three students participated in this study. The tutor was a post-doctoral fellow from a department of civil engineering where she tutors undergraduate students in how to solve shear force and bending moments problems. Student 1 (novice) was about to enter an undergraduate engineering program. She had no prior experience with this class of problems, although, she did posses the prerequisite physics background. Student 2 (experienced) had just completed his first year in an engineering undergraduate program that included a course inwhich shear force and bending moments problems were taught. Student 3 (intermediate) was also an undergraduate student who had completed his first year in a related field, but had no prior experience with these problems.

Procedure

The experimental session consisted of an apprenticeship learning situation in which each student met individually with the tutor for the purpose of learning to solve and reason about shear force and bending moments problems. Each student was taught using an identical sequence of three problems which increased in complexity. These problems were selected by the tutor. While the traditional approach to teaching shear force and bending moments problems focuses on a purely algebraic solution method, the tutor's objective for this study was to teach students a more qualitative approach. Solving these problems required constructing a series of external representations (on the blackboard): (1) drawing a beam with all of its supports and loads, (2) drawing a more abstract "free body diagram" depicting all forces acting on the beam, (3) determining the values of reactions to loads on the beam, and (4) determining and graphing the shear forces and bending moments that maintain equilibrium at each point on the beam. These areconstructed by applying a general procedure (which is to be learned) and by reasoning from knowledge of relevant principles of physics (statics). All sessions were videotaped and a record of all notations generated on the "blackboard" (actually a large pad on an easel) was kept. In addition, a copy of the tutor's lesson plan was obtained before the tutoring session.

Development of a Procedure Frame

A procedure frame describing the various steps used to solve shear force and bending moments problems was developed and evaluated in a previous study. This frame represents a declarative model of the procedure (called the "procedure frame") in which nodes represent procedures and links relate procedures in terms of *decomposition* into and *disjunctive* choice of subprocedures, and *conditional* and *temporal order* constraints on their execution (Figure 2).

Transcription and Coding of Data

All discourse that occurred in the tutorial sessions was transcribed and divided into conversational turns and main clause segments. Successive representations generated on the black-board were transcribed into graphics on cards in a HyperCard stack, and each card was cross-referenced to discourse segments that accompanied its blackboard representation.

Segments were coded in terms of response categories that correspond to the main constraints on the production of discourse identified in the situated discourse model (Figure 1). First, to analyze the conversational structure, a modified version of Dore's (1980) coding system was used to classify each discourse segment into a type of conversational act (C-act) (*assertions, requests, performatives, and organizational devices*). Percents of segments initiated by the tutor were obtained. Second, to study the participants' use of procedural knowledge to control the content of their discourse, the tutor's and the student's discourse segments (together with concurrent actions on the blackboard) were matched to nodes (i.e., subprocedures) in the procedure frame. These were also classified by: (a) the level of the subprocedure in the decomposition hierarchy, (b) the semantic fields that were used to describe each subprocedure (*act, goal, initial state, situation, conditions, instrument, result,* or *evaluation of results*), and (c) concurrent problem-solving activities that accompanied the discourse segment (*planning, testing, evaluating, interpreting, executing,* or *explaining*). Third, the tutor's discourse segments were coded according to type of pedagogical strategy employed (*instruction, demonstration, explanation, comprehension check, hint, evaluation, question*). Finally, the tutor's instructional plan was studied by analyzing the sequence of subprocdures identified in her plan and used in the session.

Discourse "fields" consisting of sequences of thematically-related discourse segments were identified. Proposi-

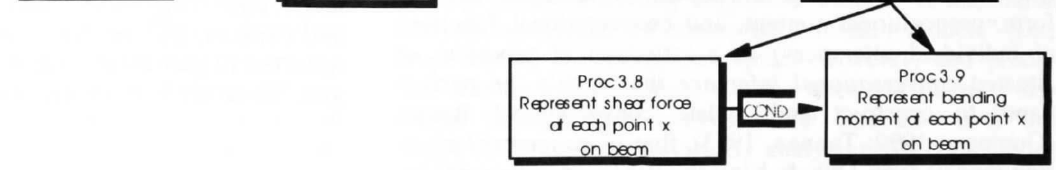

Figure 2: Top level structure of the procedure frame model.

tional analysis and conceptual graph modeling techniques were applied to these fields to study the *types of situation models*, that is, the types of conceptual and procedural knowledge that were displayed by the tutor. Tutorial discourse for Problem 1 was also analyzed by matching segments and actions to nodes and semantic fields in the procedure frame to examine how the tutor described the procedure. The tutorial dialogue for Problems 2 and 3 was analyzed in the same manner to evaluate: (a) the procedures applied by individual students to solve Problems 2 and 3 (procedures learned from Problem 1 and applied to the new problems), and (b) the types of tutorial assistance provided by the tutor to the student.

Results

Quantitative Analysis of Tutorial Interaction

Log linear models were used to quantitatively investigate the predictions of the model. In lon-linear analysis, the individual utterance (discourse segment) is taken as the sampling unit (response) and the model predicts the categories of individual discourse segments (responses). This statistical method allowed the estimation and testing of interactions of Students (1-3) and Problems (1-3) with each response coding (i.e., set of Response Categories) in predicting cross-tabulated frequencies of discourse segments in each category of response. A significant interaction of Problems with a particular Response Category would indicate that frequencies of each response category depended on the particular problem being studied; a significant interaction of Students with a particular Response Category would indicate that frequences of the response categories were different for (i.e., adapted to) particular students; and a significant triple interaction would indicate that student differences depended on which problem was being studied in the sequence. Significant main effects of Response Categories would indicate consistent effects of the response category on response frequencies across problems and students. An alpha level of .01 was adopted to determine statistical significance.

The stucture of conversational interaction. Analysis of frequencies of *tutor-initiated* vs. *student-initiated discourse* revealed a dramatic shift from tutor initiated dialogue (for Problem 1), to student-initiated dialogue (for Problems 2 and 3). Analysis of *types of C-acts* used by the tutor also revealed a significant shift from Problem 1 to Problems 2 and 3: the tutor's C-acts for Problem 1 were consistent across students and emphasized *assertions*; in contrast, her use of C-acts for Problems 2 and 3 involved fewer *assertions* and patterns of conversational interaction that varied across students and problems.

Use of pedagogical strategies to control conversational interaction. One explanation of this shift in the conversational control from teacher- to student-initiated is that these patterns reflect different high-level tutoring strategies for Problem 1 as compared to Problems 2 and 3. Such a shift should be reflected in different patterns of local pedagogical strategies. Analysis of problem differences in pedagogical strategies for the three problems did indeed reveal a significant interaction. For Problem 1 the tutor consistently emphasized strategies of *instruction*, *demonstrations*, *explanations*, and *comprehension checking*, across students; however, for Problems 2 and 3 there was a shift to *evaluation* and *hints*, with different patterns across students and problems. These dramatic shifts in pedagogical strategies were consistent with the use of a global tutorial strategy of tutor-initiated "modeling and explanation" for all students on Problem 1, followed by a strategy of "coaching and evaluation" in a context of student-initiated problem-solving on Problems 2 and 3. Further analyses demonstrated that the various pedagogical strategies were related to specific patterns of use of different types of C-acts.

Plan-based control of tutoring. Given evidence that the teacher adopted a modeling and explanation strategy for Problem 1, we investigated *plan-based control* of the tutor's discourse by matching her discourse segments for Problem 1 to subprocedures in the procedure frame. If a subprocedure node was included explicitly in the tutor's plan, it was coded as planned; if a matched subprocedure was not in the plan, it was coded as unplanned. A log-linear analysis revealed that the tutor favored planned procedures in her discourse and did so consistently across subjects. Furthermore, she tended to introduce and teach procedures in the sequence that was established by her plan. A qualitative analysis showed that departures from the planned sequence consisted principally of backtracking and reference to procedures not included in the original plan.

Explaining and modeling problem-solving procedures and reasoning. One of the most important predictions of the situated discourse model is that the content of tutorial dialogue will reflect the structure of the tutor's knowledge of the procedure, her declarative (physics) knowledge, and the integration (linking) of physics knowledge through explanations of the physical principles that define the situation in which a particular subprocedure is applied. Several quantitative analyses investigated the extent to which the tutor's procedural knowledge predicted the content of her dialogue for Problem 1. First, the tutor focused differentially on the three main subprocedures for the experienced, intermediate, and novice students. Second, the tutor emphasized descriptions of high level subprocedures for Problem 1, and procedures near the "bottom" of the frame hierarchy (i.e., more specific subprocedures) in her dialogue across students. Third, for Problem 1, the tutor emphasized particular semantic fields, including: *results*, *goals*, *evaluations*, and *situation* information (in that order) in her descriptions and explanations of procedures to Students 1 and 2; for Student 3, she shifted her emphasis to *goals*, with less attention to *results*, *situation*, and *evaluation*. There was evidence from the students' dialogue for Problem 1 that this difference reflected an adaptation to a consistent preference on the part of Students 1 and 2 for *result* descriptions, and a preference for *goal* information by Student 3 in learning the procedures (i.e., different student learning strategies). Finally, we analyzed the problem solving activities of the tutor in her actual problem-solving behavior (which accompanied her dialogue). The tutor consistently emphasized *execution* of procedures, and then *interpretation* of problem features and results; she demonstrated less *explanation*, *evaluation*, *planning*, and *testing* of results. Furthermore, the semantic fields she used in describing the procedures were strongly related to the particular cognitive activity being carried out in solving the problem and to the level of the procedure in the goal decomposition hierarchy.

Tutorial support for students' problem-solving. The tutorial dialogues for Problems 2 and 3 consisted principally of dialogue accompanying students' problem-solving episodes. Their problem-solving actions and accompanying dialogue were matched to nodes in the procedure frame and counts were made of percent of nodes referred to by students with no help from the tutor, and those with help from the tutor. All students were able to solve these problems (which required transfer of learned procedures and knowledge to new problems in the domain that increased in complexity) with help, and the novice required more help than the other two students. The extent of help from the tutor varied with student and from the simpler (Problem 2) to the more complex problem (Problem 3). Analyses of thecontent of the tutor's dialogue were carried out to examine the types of coaching and assistance she provided to the students. These analyses revealed that: (a) she focused on different subprocedures with different students, (b) her emphasis on describing low-level and high-level procedures was different for different students and different problems; and (c) she shifted from results-based to evaluation-based descriptions of the procedures.

Qualitative Analysis of Discourse Content

One example will be given to illustrate the types of conceptual situation models that the tutor represented in her situated discourse and action. In this example (Figure 3), the tutor explained the meaning of a particular representation that had just been written on the blackboard. The diagram is a "free body diagram" of a beam with two supports, two loads (one concentrated and one uniformly distributed), and two reactions (the arrows pointing upwards). The beam has been cut at point x, and the tutor is explaining the forces (shear force and bending moment) acting at the cut. The conceptual graph represents the content of the tutor's explanation, and the unlabelled arrows from nodes in the graph point to components of the free body diagram that were referred to in the tutor's description. The tutor's situation model, thus, makes the external representation meaningful by linking it to conceptual information in the situation model for the physical system being represented (forces acting on the beam at the cut).

Other types of situation models were also characteristic of the tutor's discourse, particularly: (a) explanations of the physics of static systems in equilibrium and the principles governing them; (b) modeling of reasoning used to derive equations, plots of shear forces and bending moments, or explain results; and (c) descriptions and explanations of procedures. Situation models describing static physical systems (a) typically consisted of propositions representing such information as classifications of types of forces, the structure of beams, principles of equilibrium, definitions of complex concepts, and mathematical properties of static systems in equilibrium. Causal, conditional, and logical implications were a salient characteristic of these models, as were algebraic descriptions of their quantitative properties. Models of reasoning (b) typically consisted of chained conditional relations proceeding from abstract physical principles to statements about the properties of the specific system being described. Explanations of procedures (c) consisted of, first, a sequence in which specific procedures were applied and explained, and second, conceptual information related to the various semantic fields for procedures previously described. There was smooth integration of declarative and procedural knowledge in these dialogues, and some of the procedures acted merely as a guide to a reasoning process. Thus, the complex nature of cognitive activity and integrated knowledge in this domain was strongly reflected in the content of the tutorial dialogues.

Conclusions

This study set out to apply a model of situated discourse to analyze tutorial dialogue in a complex though well-defined domain of problem solving in engineering. Quantitative analyses of the tutorial dialogue affirmed that the constraints on situated discourse processing identified in the model were strong predictors of the propositional content and conversational functions of utterances produced by both the tutor and the students. Qualitative analysis of the conceptual content of the tutor's dialogue for Problem 1 revealed several recurring and distinct types of situation models that constituted the meaning associated with the situated discourse and action. Trace analysis of the dialogue accompanying problem solving actions enabled us to ana-

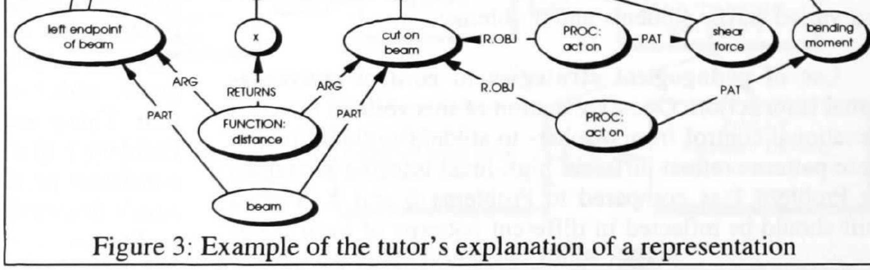

Figure 3: Example of the tutor's explanation of a representation

lyze how the tutor described the procedure, in what sequence, and how procedures were explained by linking them with declarative domain knowledge and semantic descriptions of external representations. Thus, the situation models "presented" to the student integrated declarative and procedural knowledge, and tied it to actions of applying procedures and reasoning. The students initially (Problem 1) "received" this information, their participation consisting mostly of observing, asking questions and participating in carrying out low-level algebraic procedures with tutorial guidance. Students' problem solving and dialogue on subsequent problems (2 and 3) displayed that they had acquired sufficient declarative and procedural domain knowledge and practice in its use to enable them, with varying degrees of assistance, to solve new problems. These results demonstrate that cognitive models of discourse processing can be extended to the analysis of tutorial dialogue to provide detailed information about the conceptual situation models involved, and the processes used by the tutor and students. Tutorial dialogue is similar to protocol data in studies of problem solving: it is a rich natural source of information about the processes and knowledge involved in situated learning. Such study of situated tutorial dialogue can uncover the characteristics of situations and how they constrain the cognitive processes involved in situated learning.

Acknowledgements

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