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Investigation by Design: Developing Dialogue Models to Support Reasoning and Conceptual Change

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Abstract. Theories of learning suggest that dialogue is important in shaping conceptual development. However, there is widespread debate as to the *forms and content* of educational dialogue and the *roles* participants should play in them. In addressing these issues we have adopted an approach of 'investigation by design'. Based on an examination of dialogue from case studies of tutoring in physics, we have abstracted a semi-natural set of dialogue moves thought to be effective, and designed them into system-user interaction scenarios aimed at supporting learning. This approach focuses on patterns of interaction emerging as possibly effective and refines them to render them computationally tractable. For this we adopt dialogue game theory as a design paradigm. Debating style dialogue games are applied according to a formal pedagogic framework called 'learning as knowledge refinement'. This specifies a collaborative framework for argumentation aimed at stimulating belief revision, and conceptual change. In this framework the learner adopts the role of an 'explainer' whilst the system plays a facilitating role and these participants collaborate to develop a shared explanatory model of a qualitative physics domain. A prototype CoLLeGE (Computer based Lab for Language Games in Education) system implements the framework and validates the model. An empirical study using CoLLeGE demonstrates the educational potential of the approach.

WHY INVESTIGATE DIALOGUE?

Theories of learning have long suggested that dialogue has an important role to play in shaping conceptual development. Vygotskii (1934, 1974) emphasised the role which interaction with a more mature adult (tutor) or peer could play in the transition from naïve to scientific conceptualisations. Such dialogue, through dialectic processes exemplified by the tutor and internalised by the learner, are said to come to guide the learner's reasoning (see for example Tudge, 1990).

More contemporary researchers have asked, specifically, what kinds of dialogue and what kinds of social interaction, or group settings and tasks, are important in determining when such processes will be successful in yielding meaningful conceptual change or the development of transferable reasoning skills. Answers to these questions gained from empirical investigation have as yet been partial (Edwards & Mercer, 1987). Moreover, as a result of developments in Computer Mediated Communication (CMC), new questions have been generated concerning the ways that differences between communication with and through computers alter interaction and might, hence, impact upon learning outcomes (Littleton & Light, 1998). There is, thus, a need to examine and investigate the features that make educational dialogue effective in ways that inform the development and use of computer systems that support learning.

WHAT SORT OF DIALOGUE SUPPORTS CONCEPTUAL DEVELOPMENT?

It is well recognised that in many learning contexts, particularly in the sciences, students have alternative, everyday conceptions about the world—derived from their prior experience—that impede the development of scientific understanding. These 'alternative conceptions' often require discussion and argumentation to bring about the belief revision and refinement of knowledge that leads to conceptual change and development. For example, in the conceptual change in science project (Twigger et al., 1991; Hartley, Byard & Mallen, 1991), physics modelling exercises had to be supported by argumentation with a tutor if students were to overcome pervasive alternative conceptions related to force and motion, such as those discussed by Gunstone & Watts (1986) and Clement (1982). Interestingly, in some of these studies (Twigger at al., 1991; Hartley et al., 1991) the tutor's interventions critiqued the students' explanatory accounts by pointing out incomplete explanations and inconsistencies entailed by their assertions or made further inquiries instead of informing them of a 'correct' answer (Hartley, 1998; Hartley & Ravenscroft, 1999). Palinscar and Brown (1984), have also suggested that for learning to be meaningful, the tutor offering an explanation may not always be the best approach, but rather, students should be encouraged to 'inquire' in a systematic way—that helps them to generate and test explanations for themselves. Along these lines, Pilkington & Parker-Jones (1996) revealed that a tutor can increase the learner's reasoning and reflection by *not* answering questions, but instead, reflecting inquiries back to students—an observation that is consistent with Chi, et al.'s (1989) work on self-explanation. These and similar studies demonstrate that a collaborative dialectic in which the tutor plays a facilitating inquiry or critiquing role may, in some instances, be more effective than 'conventional' teaching in bringing about conceptual change.

Although there remains widespread debate as to the form which dialogue should take to facilitate conceptual development, research which adopts dialogue analysis techniques is beginning to suggest when and why tutor talk might be particularly helpful. From work investigating natural educational dialogues that have the aim of changing student conceptualisations in a variety of situations, some consensus is beginning to emerge as to the strategies and speech acts (sets of moves) which are likely to be important.

For example, using the DISCOUNT Dialogue Analysis scheme (Pilkington, 1999), which includes Exchange Structure, Move (Speech-Act) and Rhetorical analyses, it is possible to determine which participants are active in dialogue and in what ways. DISCOUNT has been used to give insights into collaboration in natural and CMC dialogue contexts (see e.g., de Vincente, Bouwer & Pain, 1999; Pilkington, Treasure-Jones & Kneser, 1999). From these and similar studies there is evidence that 'successful' exchanges are more likely to include clarifying, challenging and justification moves. Mercer and Wegerif (1999) refer to "exploratory talk", others refer to argument or "constructive conflict" (Kuhn, Shaw and Felton, 1997); these moves are significant in both. Another move often associated with successful exchanges is hinting. From a more detailed analysis of the co-occurence of these speech-acts and their position within exchanges we can begin to suggest common strategies for directed lines of reasoning which tutor and student(s) engage in (see Katz, 1997).

WHY INVESTIGATE BY DESIGN?

The studies described above all suggest the potential of dialogue analysis for revealing important insights into educational argumentation and collaboration. However, there is much still to investigate both in natural and CMC contexts before we can be confident about the relative importance of the factors discussed above or the reliability of these findings (Van Lehn, 1992; Chi, 1997). Nevertheless, given that dialogue can facilitate conceptual development, there is a need to investigate whether intelligent systems can be designed to engage their users in such dialogue. A more direct approach to this problem, and the one adopted here, is to *investigate by design* - to take some of the features of successful dialogue (as yet not fully proven to be effective), and actively design them into interaction scenarios aimed at supporting learning. Once we have such a model we can evaluate its effectiveness, and systematically vary the roles, strategies, tactics and moves adopted to further explore their utility in guiding learners toward more scientific and systematic reasoning.

The DISCOUNT scheme describes many different moves and rhetorical relations seen in dialogue and provides a useful abstract representation of these features. By re-combining these features at different levels, different strategies for supporting learners through interaction can be modelled. However to build such models, DISCOUNT type descriptions must be made prescriptions, and combined with decision making processes to plan turns. Moreover, in order for such planning to be made possible the system needs to be able to categorise input according to its speech-act function. Since, currently, intelligent systems lack the ability to reliably parse natural input in this way, an interaction language had to be designed through which the user would explicitly indicate to the system the type of speech-act (move) they were making. The design paradigm that enables this is Dialogue Game Theory (DGT). This approach is elaborated below.

The dialogue game paradigm

The aim of the research reported here was to develop and validate a dialogue model—from a computational and educational perspective—before proceeding to develop a cognitive tool suitable for use with students. For this we found the most promising approach lay in extending the Dialogue Game Paradigm to meet the needs of the qualitative physics context.

Levin & Moore (1997) used the term *dialogue-game* to characterise observable patterns in human dialogue, which they called “Metacommunication Structures for Natural Language Interaction”. Examples of their games include Helping, Information-seeking, Information-probing and Instructing. A more prescriptive approach to dialogue games has been proposed by Mackenzie (1979), Carlson (1983) and Hintikka (1984), that have been reviewed by Walton (1984). This category of game assigns participant roles, specify goals of the interaction, and include rules that govern permissible dialogue moves for participants. Rules also specify the influence of moves on commitment stores, turn-taking and who has the initiative. Based on the MacKenzie ‘DC’ game, Moore (1993) examined how formal (logical) dialogue games could be used in the context of Intelligent Tutoring Systems (ITSs) to support fair and rational debate, and Pilkington, Hartley, Hintze & Moore (1992) demonstrated how this game could be implemented in a computer interface. More recently, Pilkington & Mallen (1996) used discourse analysis techniques to generate prescriptive ‘inquiry’ and ‘debating’ games for simulation-based learning. Two other research projects have combined elements of DISCOUNT with a DGT framework to model dialogue (Burton, Brna & Treasure-Jones, 1997; Bouwer & Pain, 1999). These projects demonstrate the potential of the approach.

The features of dialogue we consider particularly interesting are the argumentative moves associated with directed lines of reasoning, particularly dialogue which exemplifies the role of the tutor as a model inquirer. We note that much related research on peer collaboration has suggested a need for symmetry in role for successful learning gains (Blaye, et al., 1991; Lund & Baker, 1999; Burton, Brna & Pilkington, 2000). However this contrasts with the need for interaction with a more mature peer or tutor expressed by Vygtoskii and the research cited above that shows the value of asymmetrical dialogue games in which the tutor adopts an inquiring or critiquing role whilst the students do the explaining. Therefore, our research interest was in investigating tutor-led directed lines of reasoning and associated roles shown to be effective in the studies discussed above. A future goal might be to test whether there are emergent consequences for learning if the moves are made equally available to both participants.

To study the types of dialogue we are interested in modelling we first revisited protocols of a human tutor interacting naturally with students. These dialogues were taken from studies of conceptual change in science (Twigger et al., 1991). A small corpus of ten dialogues about the physics of motion was examined for patterns of interaction implicating measured improvements in conceptual change. An example illustrating the type of interchange that we were interested in modelling is given below. This demonstrates how a facilitating tutor (T) deals with a 'classic' alternative conception experienced by a student (S), that 'a net push force is needed to maintain the motion of a body' (Clement, 1982; Gunstone & Watts, 1986; Hartley, 1998).

1. T. What is the condition for the box to move at constant speed?

2. S. The person's push greater than friction causes the box to have constant speed.

3. T. What causes the box speed to increase?

4. S. The person's push greater than friction causes the box speed to increase.

5. T. Now there is a contradiction, because you have given the same cause, a push greater than friction, for different effects, the box speed constant and the box speed increase. Can you resolve this?

6. S. Ok, I think that the person's push greater than friction causes the box speed to increase.

7. T. If the person's push greater than friction causes the box speed to increase. Isn't it the case that a person's push equal to friction is a condition for the box speed to be constant?

8. S. Yeh, the person's push equal to friction is a condition for the box speed to be constant.

In turns 1 – 4, we can see how the tutor elicits an explanation that is a manifestation of this incorrect alternative conception ('person's push greater than friction causes the box to have constant speed') and then entraps the learner through acquiring another contradictory explanation that is consistent in terms of the Physics ('person's push greater than friction causes the box speed to increase'). After explaining the rationale for the contradiction (i.e. that they have given the same cause for different effects) the tutor requests its resolution in turn 5, and the student responds by re-asserting the consistent explanation ('push greater than friction causes the box speed to increase'). The tutor then uses this latter (consistent) explanation in a persuasive manner, presenting it as a support for a consistent explanation—in terms of the Physics— presented to the student as a counterfactual question 'Isn't it the case that a person's push equal to friction is a condition for the box speed constant' in turn 7. Whereupon the student asserts this consistent explanation in turn 8, and in doing so, hopefully revises their conceptual model of this context.

We can see that this type of dialogue interchange is both facilitating and dialectical, because the tutor 'works with' the explanations acquired from the student whilst stimulating them to refine their model without using didactic expositions. Instead, the student's own contributions are considered in terms of the underlying 'logic' of the domain, that is used in such a way (e.g. through pointing out contradictions and likely implications) that they are assisted to refine their conceptual model for themselves. In brief, we have a co-operative and non-adversarial tutoring dialectic.

In our asymmetrical facilitating dialogue-game (hereafter *f* dialogue-game) the computer system plays the role of a facilitating 'tutor' and the learner the role of explainer, with the dialogue managed under a dialogue game framework. This management framework allows a structured and constrained dialectic to be maintained in which the learner is stimulated to express and refine their qualitative causal explanations of an event, to form more complete, consistent and general explanatory models. Technically, this is realised by the system facilitator having an abstract qualitative 'world' model—with 'commonsense' reasoning rules linked to dialogue strategies and tactics. Additional rules manage focus and coherence in accordance with the pedagogic objectives. Participants share an 'interaction language' and conduct the discourse using pre-defined dialogue moves. These design components are described in the next section.

THE DESIGN AND IMPLEMENTATION OF THE DIALOGUE MODEL

A prototype CoLLeGE (Computer based Lab for Language Games in Education) system implements the pedagogic and dialogue game framework called "learning as knowledge refinement" (Ravenscroft, 1997). The design and implementation of this *f* dialogue-game are described below.

An overview of the CoLLeGE architecture and implementation

The current CoLLeGE system, that is written in LISP and KR (a frame based extension, see Myers et al., 1992), is in its first implementation phase, and is currently used as a dialogue modelling 'work-bench' for demonstrating and investigating the underlying dialogue processes necessary for learning as knowledge refinement. Figure 1 presents an overview of the CoLLeGE architecture.

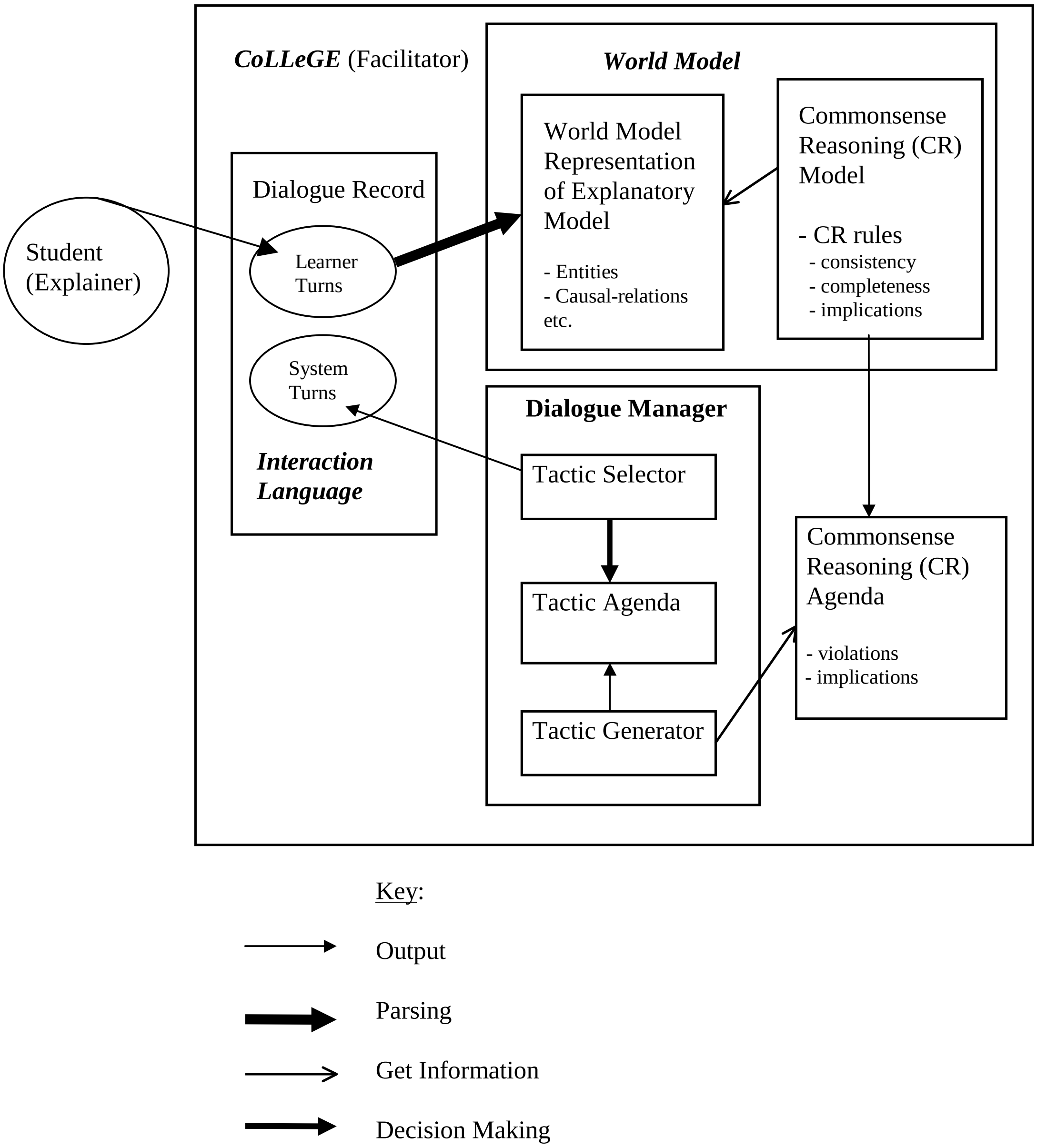

Figure 1. The CoLLeGE architecture

To play its facilitating role in the dialogue the system parses the students utterances into generic 'world model' representations. These are input to a qualitative 'commonsense reasoning' (CR) model that generates output—in the form of constraint violations and implications—to a 'commonsense reasoning' agenda. The latter is input to the dialogue management component, that generates repertoires of legitimate dialogue tactics and posts them to an agenda—where they are organised according to a pre-defined dialogue strategy. Finally, to perform its turn in the discourse and realise the dialogue strategy the system applies maxims and heuristic rules to decide which particular tactic to deploy.

The CR and Tactic Agendas are generated each time the learner passes over the initiative, whereas the contents of the Dialogue Record and World Model Representation accumulate during the interaction. Thus, a game is over when the CR and Tactic Agendas are 'empty', meaning all the system's goals have been addressed. Alternatively, impasses may be reached when the student is unable to refine their model in response to the tactics of the system. In this case, a critique remains in the CR Agenda and goals remain to be addressed; how this might be dealt with is considered in the section outlining further work and discussed in Ravenscroft (1997). The design components are described in detail below.

The generic world model

It is well attested that 'conventional' domain modelling approaches give rise to difficulties because they require intensive knowledge engineering and, unsurprisingly, produce domain specific systems. An additional problem in our case, that is common in many learning scenarios, is that students may use unanticipated vocabulary to express the same underlying conceptual models (e.g. on occasions they use 'pressure', 'energy' etc. as synonyms for 'force'). Instead of attempting to anticipate and 'correct' learner's vocabulary through using pre-stored representations, it is arguably better to work with the concepts that they introduce, as these are closer to 'what the students are thinking'. In addressing these issues, we designed a 'generic domain model', that can reason about the concepts and explanations that the student introduces without resorting to pre-stored 'domain level' content, and give emphasis in the dialogue to the causal and logical coherence of student's explanations and how to abstract or generalise the model. So, to interpret and reason about the learners' utterances we have developed an abstract ontology (Ravenscroft, 1997) of the physical world in which the event scenarios are placed. The system has a view of a world of Entities, that may have (learner assigned) Names, Properties, Behaviours, and Actions—which link to other Entities, and which can have assigned qualitative values (e.g. small, medium, large, increase, decrease). At the design level, this ontology is represented by objects, and causal relations link these 'states of the world'. So, taking a 'classic' incomplete and inconsistent explanation from the physics of motion domain, that demonstrates the common view that a 'push' (completely) regulates the motion of a body[I]:

'person's push is zero (i.e. push stops) on the box causes the box speed to decrease'

This is represented as:

Entities

:Name	[person]	:Name	[box]
:Properties	[..]	:Properties	[speed]
:Behaviours	[..]	:Behaviours	[..]
:Actions	[push]	:Actions	[..]

[I] Note that this is also a manifestation of the alternative conception of, 'force $\Rightarrow$ motion' (i.e. a corollary of it, that 'no force $\Rightarrow$ no motion').

Causal-Relations

:type [causes]
:antecedent [Action
    :Name [push]
    :Entity [person]
    :quantity value [zero]
    :quantity-change value [..]
    :activity-status value [..]
:consequent [Property
    :Name [speed]
    :Entity [box]
    :quantity value [..]
    :quantity-change value [decrease]
    :quantity-change-quantity value [..]

There are two Entities, [person] and [box], where [person] has an :Actions attribute with value [push], and [box] has a :Properties attribute with a value [speed]. The Causal-relation of :type [causes] has an :antecedent attribute with a value that is the Action :Name [push] of an :Entity [person] with a :quantity value [zero]. This is related to the :consequent attribute with a value that is a Property :Name [speed] of an :Entity [box] which has a :quantity-change value [decrease].

Therefore, these representations specify a state of the world expressed at a particular time in the dialogue. Causal-agents, that include Abstract-agents (e.g. friction, force, gravity) and Actions (e.g. push, kick, throw), can change or assign a state to an Entity. Essentially, by representing the learners' explanations within this object-oriented ontology, the system can reason with a conservative amount of abstract knowledge, specified in terms of the generic taxonomy.

A commonsense reasoning (CR) model

Causal relations between states in the world model are specified according to a Commonsense[II] Reasoning (CR) model that includes five axiomatic laws of agency, effect, equilibration[III], completeness and generalisation. These share some similarities with the notion of topoi (Dieng, Corby & Lapalut, 1995) and can be considered as a 'target model' (Van Joolingen, 1995) for learner beliefs. The CR model, and a full representation of its inclusive laws are specified in Ravenscroft (1997). An axiom representing the Law of Agency is:

'If there is a Causal-agent, it is related to a consequent State-change, and likewise,
if there is a State-change, it is related to an antecedent Causal-agent.'

Colloquially this states that an effect is a consequent of an antecedent causal agent, and if a causal agent is active a consequent state change is expected. A CR rule derived from this axiom is:

(State-change)q $\Rightarrow$ (Causal-agent)p related to consequent (State-change)q
e.g. box speed increase $\Rightarrow$ (Causal-agent)p related to consequent box speed increase

[II] "Commonsense" is perhaps a dangerous term to use as it is ill-defined and carries with it certain expectations. In this case it represents and applies plausible principles of causality (suitably defined), that are qualitative in nature, to which people would normally consent, e.g. each and every effect has a cause(s).
[III] "equilibration" refers to relationships where concepts that have a quantity act in opposition to each other, e.g. where a push force acts against friction.

This means that although the system has no specific domain knowledge to begin with—since this will be acquired through the discourse—it does represent knowledge about abstract relations, such as the relationships between Causal-agents and Entity State-changes. Hence, by classifying incoming domain concepts (e.g. force, friction, push) as Causal-agents and Property or Behaviour changes (e.g. speed increase, move decrease) as State-changes, the system can reason about student explanations without prior knowledge of the specifics of the domain. The other laws are:

- Law of Effect ‘The greater the Causal-agents quantification-value, the greater the causal effect—and the converse also holds.’;
- Law of Equilibration ‘If Causal-agents belong to the same (general) class their effect values can be added—a resultant effect. Specifically when agents produce equal and opposite effect values, then the resultant is zero—an equilibrium condition.’;
- Law of Completeness ‘If a quantification-value is given in a causal relation, then the full range of values for those given are represented (i.e. provided or inferred) in causal relations.’;
- Law of Generalisation ‘Differently-named Causal-agents causing effects to the same property belong to the same (more general) class of agents.’.

Reasoning about explanations

Once the students’ explanations are interpreted and classified according to the world ontology, these instantiated objects are accessed by the commonsense reasoning model that evaluates the learners’ contributions and generates a critique in a commonsense reasoning agenda. Continuing with the example assertion considered previously:

‘person push is zero (i.e. push stops) on the box causes the box speed to decrease’

Remembering that this is a typical incomplete and inconsistent explanation. It excludes a Causal-agent for the State-change ‘speed decrease’ (i.e. which is friction, but the system would not know this), and it is also inconsistent with the world model’s law of agency, because the learner has provided an effect ‘box speed decrease’ without a cause ‘person push zero on the box’. Thus, the law of agency is violated:

(State-change)$q \Rightarrow$
(Causal-agent)p related to consequent (State-change)q

and the model generates the output:

Law of Agency Violated:
No Causal-agent (person push zero on the box), but a State-change (box speed decrease).

How the system would now respond, or what are the legitimate and useful ways to respond is a matter of some interest. The rationale and tactics related to this are discussed later.

The interaction language

The Interaction Language is a dialogue modelling representation and communication intermediary shared by the system facilitator and the learner explainer, and is fully specified in Ravenscroft (1997). The language was developed to facilitate the expression and refinement of qualitative causal explanations by the learner, and the provision of evaluative feedback in the form of critiquing and inquiry tactics by the system facilitator. Its grammar allows the learners’ utterances to be parsed into the CoLLeGE world model ontology and therefore become subject to the system’s commonsense reasoning. Pre-defined dialogue moves convey intention in the discourse, whereas pre-defined predicates and qualitative values represent semantic features. The learner uses this language to express causal explanations using a rhetorical predicate set adapted from the work of Pilkington (1992a, 1992b). The language allows 'everyday' qualitative causal explanations and more abstract, formal qualitative causal explanations to be expressed and represented. The use of these pre-defined moves (e.g. Assertion, Challenge), rhetorical predicates (e.g. Causes, Condition-for), lexical predicates (e.g. Acts-on, Has-property) and qualitative values (e.g. small, medium, large)[IV] means this language is rich enough to express types of explanation and system tactics while obviating some of the semantic problems of natural language understanding and generation. Therefore, another issue in designing this language was to achieve the right balance between providing sufficient structure and constraint to minimise semantic ambiguities whilst maintaining a degree of freedom and flexibility that did not disallow legitimate utterances. The current CoLLeGE interface implements this language using a menu and template scheme (see Ravenscroft, 1997), and although this can be used by researchers and students, future refinements will focus on HCI and usability issues.

The categories of developed moves build on previous work implementing an interface for the MacKenzie (1979) DC Dialogue Game (Pilkington, Hartley, Hintze & Moore, 1992; Moore, 1993), adapting and extending some of its moves to facilitate a richer and more flexible dialogue game. The causal rhetorical predicates are adapted from Pilkington's (1992) work applying Rhetorical Structure Theory (Meyer, 1975) within intelligent help systems. The lexical predicates and qualitative values were devised to represent, constrain and structure semantic aspects that were salient in tutoring dialogues (Twigger et al., 1991; Hartley, 1998). So, taking the same alternative conception discussed above:

'person push is zero (i.e. push stops) on the box causes the box speed to decrease'

this is expressed as;

Assertion
person push-ZERO ACTS-ON box CAUSES box HAS-PROPERTY speed-DECREASE

The explanation is an Assertion, with the CAUSES rhetorical predicate representing the type of causal relation linking the antecedent and consequent state. Where the former is represented by the ACTS-ON lexical predicate, that links the Action push—with an assigned value ZERO—of an Entity person to another Entity box. The latter is represented by the HAS-PROPERTY predicate, that assigns a Property speed—with a qualitative value change DECREASE—to the Entity box. Further examples of the interaction language and how it operates in the dialogue are given in the section describing the computational and educational validation.

Linking the commonsense reasoning to dialogue strategy and tactics

Whilst the dialogue between learners and the system is conducted through the interaction language, the facilitator utterances subserve the strategic (see Figure 2) and tactical decisions of the dialogue management component. As it seeks to interpret and evaluate the descriptions and explanations given by the students in line with its own 'understanding', CoLLeGE applies its CR rules to check that the model constructed from their contributions is i) consistent; ii) complete; and iii) sufficiently general in its scope.

Being 'consistent' means that assertions in the explanatory model do not contradict the rules of agency and effect—and that students do not contradict their own previous assertions which are not withdrawn. Having a 'complete' explanation means that the system can infer (without inconsistency) all entity property values from the Causal-agents and their effects that have been proposed, and so the law of completeness is not violated. The criterion of being 'general' is to ensure that the general classification of agents has been made for those causing

[IV] Note that these qualitative quantity values can have changes attached (e.g. increase, decrease) and relations applied to them (e.g. greater than, less than, equal to).

effects to the same entity properties (i.e. law of generalisation exercised), and also that the law of equilibration has been appropriately applied.

It is expected that students are familiar with the domain concepts (e.g. the physics of motion), but to determine how to relate its diagnostic appraisal of students' explanations to its responses, the system requires tactics that link the strategic objectives of consistency, completeness and generality to the interaction language. Following the conventions of the dialogue game, each possible CR 'state' subserving these objectives is represented in a Goal/Sub-goal hierarchy (in Figure 2) that is traversed—from top-to-bottom and left-to-right—to realise the system's dialogue strategy. This hierarchy includes sub-goals such as *Address_agency_violations*, *Check_inferred_equilibration_relations* and *Acquire_general_agent* that are illustrated in the dialogue excerpts described in the section reporting the validation studies. The system's tactics (*e.g. Challenge-construct*, *Probe-question*, *Persuade*, *Resolve*, *Acquire-construct*, *Assume*) manage the discourse by linking (lower level) moves/predicates to these (higher level) strategic sub-goals concerned with violations, deficiencies and implications in the developing model.

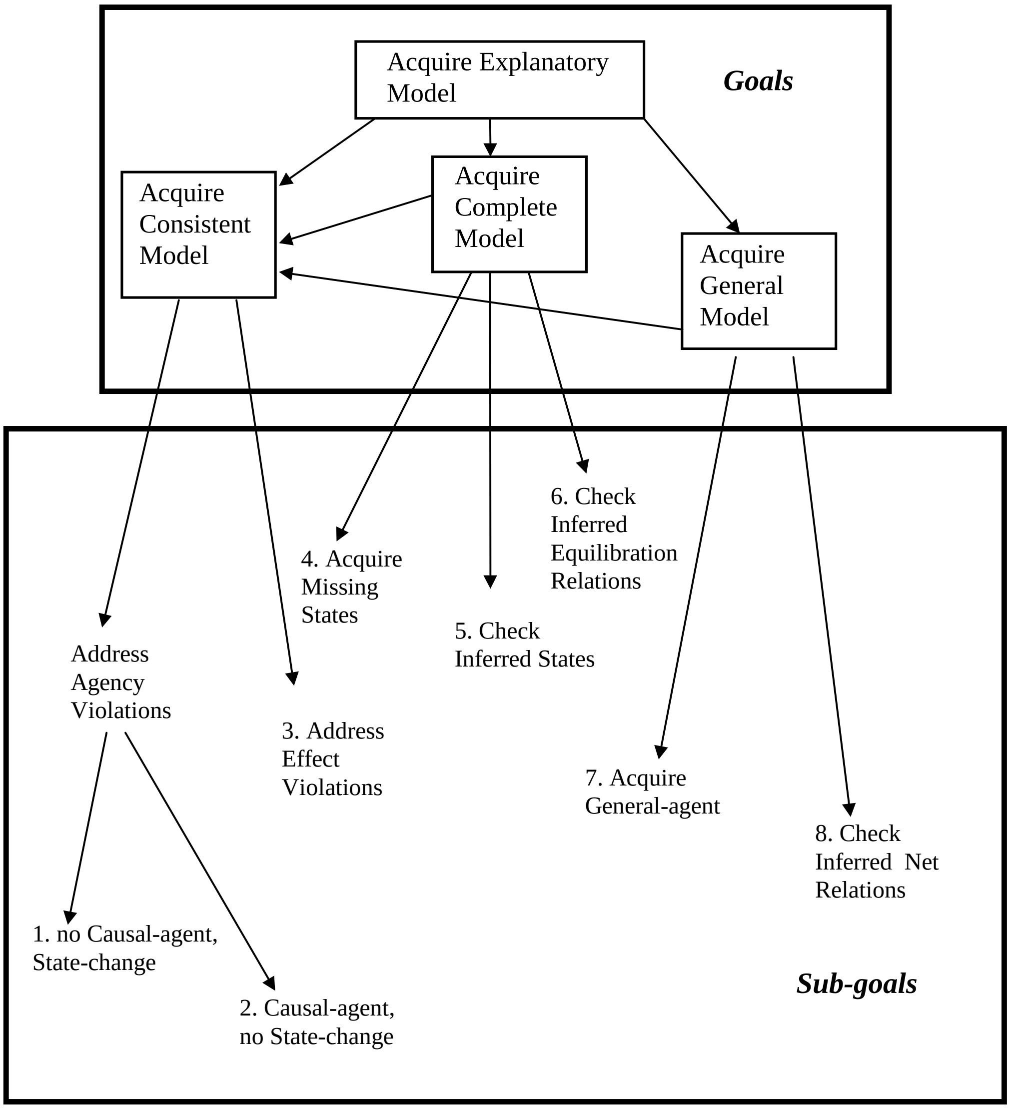

Figure 2. Goal/Sub-goal hierarchy specifying dialogue strategy

An example of a *Persuade* tactic—as it is implemented in the CoLLeGE computer system—is given below. This is generated in response to a manifestation of the alternative conception 'force ⇒ motion' that was considered earlier, that is 'a push greater than friction causes box speed constant' expressed in an Assertion *x2*.

Goal:- ADDRESS-AGENCY-VIOLATION
Tactic:- **Persuade**
In assertion ASSERTION *x2* you have given a causal agent, no state change.
In Assertion:- ASSERTION *x1* Abstract agent push > Abstract agent friction : causes
box has property speed. *Change:* constant
Isn't it the case that:
Abstract agent push = Abstract agent friction : is a condition for
trolley has property speed. *Change:* constant

In this example the Persuade tactic addresses the strategic sub-goal ADDRESS-AGENCY-VIOLATION. It refers to the violating explanation (ASSERTION *x2*), critiques it in terms of the world model 'you have given causal agent, no state change.', and poses a consistent 'version' of the offending assertion—that is a system implication—as a counterfactual question 'Isn't it the case that: Abstract agent push = Abstract agent friction : is a condition for trolley has property speed. *Change:* constant'; where this question is prefaced by the previous student assertion (*x1*) that generated the implication.

However, in dealing with this sub-goal of 'Address agency violations (causal agent but no state change)' as well as this 'Persuade' tactic, a 'Challenge-construct' tactic could also be performed leading to:

*'You have given a cause (push > friction) without an effect (box speed constant).
So (What) is the effect of push > friction?'*

Alternatively, simple 'Probe' tactics could be used:

'Is it the case that push = friction is the condition for box speed (to be) constant?'

'What is the consequence when push = friction?'

Or an 'Assumption' might be suggested:

'Let us assume that push = friction is a condition for box speed to be constant (no change)'

and in this latter case, the implications of the explanation are then explored.

Therefore, there is a *repertoire of legitimate tactics* available for addressing common conceptual difficulties. How these are implemented and presented in the interface is discussed later. A full description of tactic-sub-goal links and the formulation of tactics is given in Ravenscroft (1997).

Essentially the system adopts four main types of tactic to play its facilitating role in the dialogue, namely *Challenge*, *Probe*, *Persuade* and *Resolve*. 'Challenge' may be used when the laws of agency or effect are violated. In this case the learner is presented with a critique in terms of the system's reasoning followed by a request for another, hopefully revised explanation. 'Probe' questions students about an implication the system has made from their explanation. The 'Persuade' tactic may be issued when a law of agency or effect is violated, and there is an implicit contradiction between a system implication and the learner's assertion that caused the violation. In this case the student is presented with their consistent assertion, to establish some common ground, followed by the system's inference that was generated from the assertion (see example above). The latter is usually posed as a question and, if the learner concurs, they are requested to 'Resolve' the explicit contradiction. Additionally, the system can suggest an 'Assumption', which becomes the basis for further discussion if an impasse is reached. Several modes of expression for the tactics can be realised by the available moves and predicates.

Tactic preferences: managing focus and coherence in pursuit of pedagogical goals

Studies of transcripts collected from the Conceptual Change in Science Project (Twigger et al., 1991) and tutoring experience suggested how tactic selections could be co-ordinated to manage focus and coherence whilst pursuing the pedagogical goals of the discourse. This is represented through preference orderings of dialogue tactics for each CR state that are specified in Ravenscroft (1997). These follow a maxim of 'maximal contribution' from the learner, so the system favours *Challenges*, then *Probes*, then *Persuades* or *Resolves*, and finally *Assumes*. Similarly, heuristics specify tactic preferences to manage focus and coherence whilst addressing particular CR states relevant to the same strategic goal, these include:

- 'prefer-indirect-resolution' specifies the principle 'It is better to use indirect tactics, such as Probe, Challenge and Persuade—before directly confronting the learner with Resolve' when addressing the goals Address_agency_violations and Address_effect_violations;
- 'prefer-cause-for-effect' specifies the principle 'It is better to critique an effect without a cause (cf. a cause without an effect) and request another cause for the effect' when addressing the goal Address_agency_violations;
- 'prefer-opposite-value' specifies the principle 'If the learner has provided an explanation including a qualitative value (e.g. 'speed increase') and quantity implications have been generated (e.g. for 'speed constant' and 'speed decrease'), then Probe the opposite value next (i.e. 'speed decrease' for this case)' when addressing the goal Check_inferred_states;
- 'prefer-net-General-agent' specifies the principle 'It is better to request the effect for a net General-agent (e.g. net friction-force) before requesting the effect for no net General-agent (e.g. zero net force)' when addressing the goal Check_inferred_net_relations.

These guiding maxims and principles are demonstrated during the interchanges that are reported in the section that describes the validation studies.

Rules governing the game

Dialogue rules govern the way that the student and facilitator perform their role in the game. These cover the types of moves available to each participant and the effect these have on the commitment store along with issues of initiative and turn-taking.

Assigning moves to participants

In the current game, *Assertion* (and *Yes*), *Withdraw* (and *No*) and *Don't Know* are *explanatory* moves and the rest (*Construct*, *Question*, *Question-counterfactual*, *Challenge*, *Persuade*, *Resolve*, and *Assume*) are *facilitating* moves. Thus, the learner uses explanatory moves as they *Assert* (or accept) and *Withdraw* (or reject) explanations, and the system uses facilitating moves to critique or make further inquiries with regard to the learners' explanations. Although, in principle, a participant may use any move, it is felt that allocating them based on role is necessary for specifying this dialogue game, and similarly, assigning them differently could support other dialogue games.

The explanatory model: a shared commitment store

The explanatory model is a record of the learner's commitments in the dialogue record and the world model representation. The aim of the interaction is to produce a commitment store that is consistent, complete and general in terms of the system's CR axioms. So, the system's moves facilitate the learner to *Assert* or *Commit to* (i.e. respond *Yes*) consistent, complete and general explanations, or *Withdraw* or *Withdraw commitment* (i.e. respond *No*) to inconsistent explanations. Thus, it is the learners' moves that directly influence the explanatory model. With the exception of *Assume*, the system's moves have no direct influence on the model, although they do carry the deliberate intention to stimulate appropriate revisions and refinements. Examples of commitment rules are given below, see Ravenscroft (1997) for a complete specification.

Assert
An *Assertion* of the form - "I Assert P" - means the participant is committed to P, so P is represented in the explanatory model. An *Assertion* is also implied by an Acceptance (*Yes* response) of a question.

Withdraw
A *Withdraw* of the form - "I Withdraw P" - means the participant is no longer committed to P, so P is removed from the explanatory model. A *Withdraw* is also implied by a *No* response to a *Question* (or *Question-counterfactual*). Once a proposition is *Withdrawn* any implications generated from it are also removed.

Don't Know
Don't Know is neutral with respect to commitment, so this response means the explanatory model remains unaltered.

Initiative and turn taking

In this facilitating dialogue game, there is flexible control of initiative, that is freer than that proposed in Walton (1984) for example. Both *Assertion* and *Withdraw* are 'neutral' with respect to initiative. For example, following an *Assertion* the learner may *Pass* the initiative to the system (ceding the initiative), or use *Continue* (and maintain the initiative) to perform another *Assertion* or a *Withdraw* within the same turn. Thus, within this scheme *Pass* and *Continue* are 'initiative qualifiers'.

Note that using *Continue* only allows further *Assertions* or *Withdrawals* to be made in the same turn, so, at some point, updates to the explanatory model must be submitted, and the initiative passed over. Once the system has the initiative, it usually retains it until the learner overrides the system's control using *Continue*. This notion of an initiative qualifier is crucial, because it expands the locutionary possibilities in the dialogue game. The learner may express a series of explanations (at the beginning of the game) and then *Pass* the initiative to the system, submitting a 'complete' explanatory model. Similarly, the learner may choose to *Withdraw* a number of *Assertions* in one turn. Alternatively, a model may be acquired incrementally, via alternate turn-taking.

Beginning and ending the game

The current game begins with the presentation of an explanatory task, such as those presented in studies of conceptual change, with the learner asked to provide a causal explanation or a series of explanations for a physical event in the qualitative physics domain, for example:

"Explain the stages of motion for a person pushing and then stopping pushing a box."

“Explain the motion of a supermarket trolley being pushed along the floor.”

The game is over when the learner has provided a consistent, complete and general explanatory model *or* remains at an *impasse*. An *impasse* is the name given to a dialogue state in which the learner retains an inconsistent (or incomplete) explanatory model following ‘exhaustive’ application of the system’s tactics and the system has nothing new to ‘talk about’. How this latter situation might be handled is discussed in the section outlining further work and elaborated in Ravenscroft (2000).

The CoLLeGE interface

Currently the CoLLeGE interface consists of three scrolling windows representing the Dialogue Record, Commonsense Reasoning Agenda and Dialogue Tactics Agenda, along with the World Representation (i.e. world model classification) of the learner’s input and a series of buttons (along the bottom of the interface) for performing the dialogue. These buttons facilitate the expression of explanatory moves (i.e. *Assert*, *Withdraw*, *No*, *Do_Not_Know*), the passing of initiative (i.e. *Pass*) and the selection of Dialogue Tactics from the Agenda (i.e. *Choose-Tactic*) to perform facilitating moves; where the dialogue tactics (e.g. *Persuade*) are linked to the strategic goals they address (e.g. ADDRESS-AGENCY-VIOLATION).

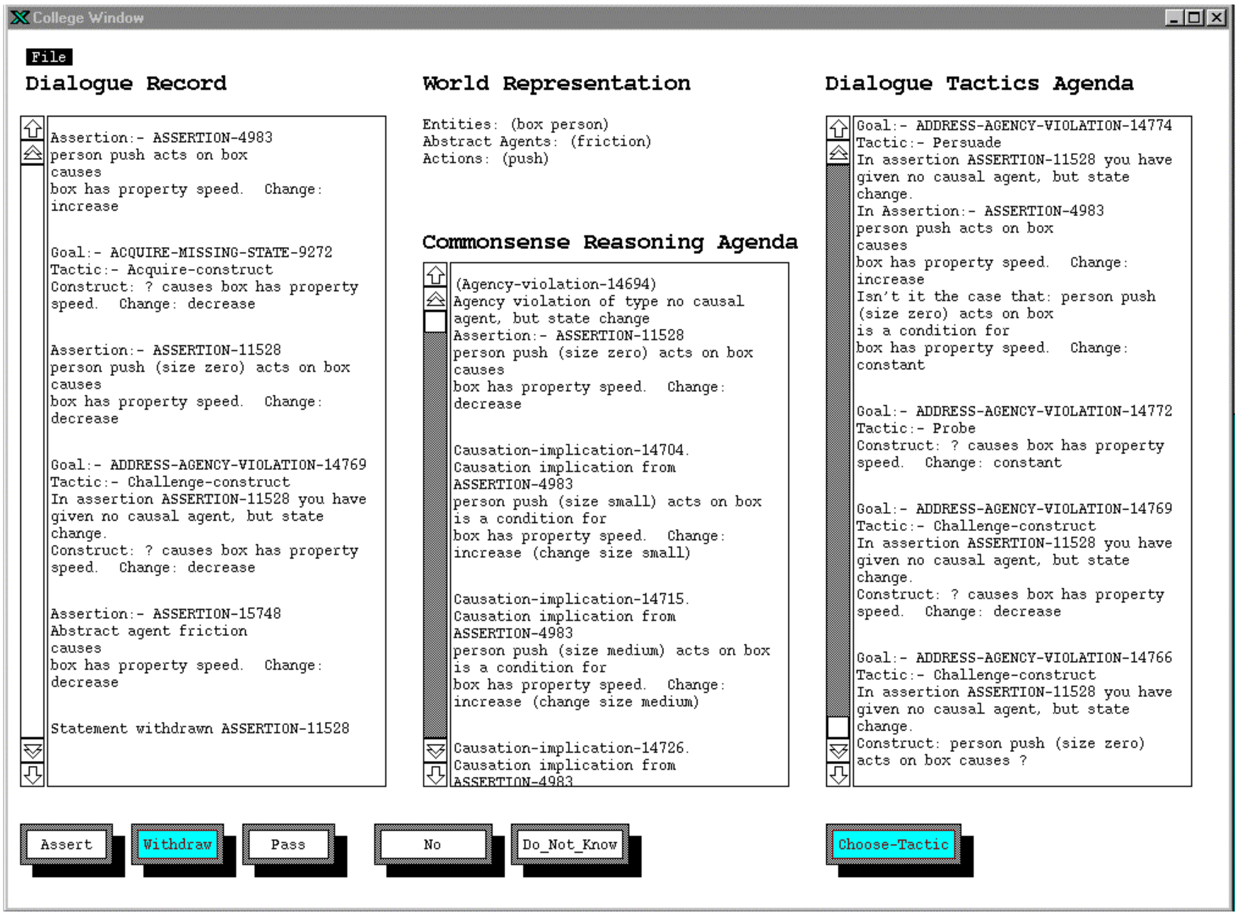

Figure 3. The CoLLeGE Interface

Each Move, Commonsense Reasoning State and Dialogue Tactic is assigned an identification number, for example, in the illustration the first *Assertion* in the dialogue record is numbered 4983; these numbers are referred to in the descriptions of dialogues in the following section.

VALIDATING THE DIALOGUE MODEL

Having developed the dialogue model that is specified in the previous section and illustrated in Figure 3, it was necessary to validate it from a computational and educational perspective. In the first case, this meant checking that the computer system did in fact model the underlying dialogue processes and generate the desired dialogue tactics. In the second case, this meant performing a small-scale evaluation study to check that the model does actually stimulate belief revision that leads to conceptual change and development.

Computational validation: have we modelled the dialogue processes?

The excerpt of dialogue in Figure 3 is typical of the early stages of some discourses that occurred during the evaluation study that is reported in the next subsection—where we describe and discuss the tactics and tactic changes of an experienced tutor. Here the emphasis is on demonstrating the implemented dialogue processes and the range of dialogue tactics that are performed by the system. The context is the kinematics scenario of ‘a person pushing a box along a supermarket floor’, that was taken from the empirical studies of conceptual change in science.

On the first turn of the dialogue the learner *Asserted* (4983) an explanation for an increase in speed of a box, where the predicates used (i.e. ‘acts on’ and ‘has property’) allowed ‘box’ and ‘person’ to be classified as Entities, and ‘push’ to be classified as an Action in the World Representation. After *Passing* the initiative to CoLLeGE, the system, in applying its law of effect, generated causation implications for quantities (i.e. zero, small, medium, large) of antecedent and consequent states, some of which (e.g. 14704, 14715) are illustrated in the Commonsense Reasoning Agenda. However, in order for CoLLeGE to complete the model, the goal ACQUIRE-MISSING-STATE required the learner to provide an explanation for the ‘box speed to decrease’, and so an *Acquire-construct* tactic addressing this goal (9272) was performed on the second turn. The learner provided an inconsistent causal explanation (11528) in response, *Asserting* a ‘zero push is a condition for the box speed to decrease’. Upon receiving the initiative CoLLeGE reasons that this *Assertion* (11528) is inconsistent with the Law of Agency and posts a critique (14694) to the Commonsense Reasoning Agenda that points this out ‘no causal agent, but state change’. Note that the system generates a repertoire of tactics for addressing this violation of the law (i.e. goal - ADDRESS-AGENCY-VIOLATION)—similar to those presented (informally) in the previous section—including *Persuade* (14774), *Probe* (14772) and *Challenge-construct* (14769, 14766) tactics, and posts these to the Dialogue Tactics Agenda. Although the deployment of any of these tactics is a legitimate response, following the specified preference orderings and the ‘prefer-cause-for-effect’ heuristic the *Challenge-construct* (14769) was chosen that requested the learner to think again and provide another cause for the given effect (i.e. ‘box speed decrease’). The learner was subsequently stimulated to introduce friction into their explanatory model, providing it as the cause for the ‘box speed decrease’ (Assertion-15748), allowing ‘friction’ to be represented in the World Representation as an Abstract Agent. In this example, the student then *Withdrew* their inconsistent assertion (11528) in the same turn. This interchange demonstrates the effectiveness of *Challenging* an inconsistent and incomplete student explanation by critiquing their *Assertion* and prompting for another, hopefully revised, explanation.

Continuing with this example, the next tactic selected (35398) uses a *Construct* move to *Probe* the learner for an explanation that confirms the system’s implication that ‘push = friction condition for box speed constant’. Whereupon the learner expresses another inconsistent explanation that is a clear manifestation of the alternative conception ‘force $\Rightarrow$ motion’, *Asserting* a ‘push greater than friction’ causes the ‘trolley speed constant’ (ASSERTION-44045).

Goal:- CHECK-INFERRED-STATE-35398
Tactic:- **Probe-construct**
Construct: ? causes box has property speed. Change: constant

Assertion:- ASSERTION-44045
person push acts on box > Abstract agent friction : causes
box has property speed. Change: constant

A different tactic is selected for addressing the Agency violation in this case, that represents an entrapment strategy. The learner is *Probed* (47237) to *Construct* an explanation for ‘box speed increase’ and when they provide the same cause (person push acts on box > Abstract agent friction) they had given for ‘box speed constant’ they are requested to *Resolve* the explicit contradiction (51973).

Goal:- ADDRESS-AGENCY-VIOLATION-47237
Tactic:- **Probe**
Construct: ? causes box has property speed. Change: increase

Assertion:- ASSERTION-48522
person push acts on box > Abstract agent friction : causes
box has property speed. Change: increase

Goal:- ADDRESS-CAUSATION-VIOLATION-51973
Tactic:- **Resolve**
There is an explicit contradiction between ASSERTION-44045
ASSERTION-48522 (same causal agent, different effect)
Resolve:-
Assertion:- ASSERTION-44045
person push acts on box > Abstract causal agent friction : causes
box has property speed. Change: constant
or
Assertion:- ASSERTION-48522
person push acts on box > Abstract causal agent friction : causes
box has property speed. Change: increase

Assertion:- ASSERTION-56461
person push acts on box > Abstract agent friction : causes
box has property speed. Change: increase

After the learner responds by (re)*Asserting* the consistent explanation (56461) another CoLLeGE tactic is selected for addressing the remaining violation, *Persuading* (60084) the learner to *Assert* a consistent explanation for ‘box speed constant’ (63849), which the learner subsequently does (ASSERTION-63849), followed by the *Withdrawal* of their inconsistent explanation (ASSERTION-44045) within the same turn.

Goal:- ADDRESS-AGENCY-VIOLATION-60084
Tactic:- **Persuade**
In assertion ASSERTION-44045 you have given causal agent, no state change.
In Assertion:- ASSERTION-48522
person push acts on box > Abstract causal agent friction : causes
box has property speed. Change: increase
Isn't it the case that: person push acts on box = Abstract causal agent friction : is a condition for box has property speed. Change: constant

Assertion:- ASSERTION-63849
person push acts on box = Abstract causal agent friction : causes
box has property speed. Change: constant

Statement **withdrawn** ASSERTION-44045

After passing the initiative, the learner is prompted to *Construct* an explanation for the remaining inferred equilibration relation (i.e. where person push is less than friction) that needs to be checked:

Goal:- CHECK-INFERRED-EQUILIBRATION-52075
Tactic:- **Probe-construct**
Construct: person push acts on box < Abstract agent friction : causes ?

and the learner enters a consistent explanation (67421).

Assertion:- ASSERTION-67421
person push acts on box < Abstract agent friction : causes
box has property speed. Change: decrease

This interchange demonstrates the value of *Probing* implications and requesting the *Resolution* of emerging contradictions in the student's model before *Persuading* them of a consistent explanation—as an alternative to directly *Challenging* an inconsistent explanation.

To summarise this interaction, the learner's initial explanatory model is incomplete (i.e. it does not include friction), the learner *Asserting* that 'a zero push causes the box speed to decrease'. This violates the law of Agency (i.e. no Causal-agent, but a State-change). To address this agency violation CoLLeGE uses a *Challenge-construct* tactic to prompt the learner to refine their model by introducing friction as an abstract agent influencing speed and *Withdrawing* their inconsistent *Assertion*. A further *Probe-construct* tactic elicits another inconsistency - a clear manifestation of the alternative conception 'force ⇒ motion', expressed as 'a person push greater than friction causes box speed constant'. This time CoLLeGE *Probes* a consistent interpretation of the inconsistent *Assertion*. A *Probe-construct* tactic requests a cause for 'box speed to increase' and when the learner provides the same antecedent state 'person push greater than friction' that they provided for 'box speed constant' they are requested to *Resolve* the contradiction. CoLLeGE points out that they have given the same cause (i.e. 'person push greater than friction') for different effects (i.e. 'box speed constant' and 'box speed increase'). In response the learner (re)*Asserts* the consistent explanation for the equilibrium state, so CoLLeGE resorts to *Persuading* the student of a consistent interpretation (i.e. 'person push equals friction causes box speed constant') to redress the inconsistent *Assertion* (i.e. 'person push greater then friction causes box speed constant'[V]). The learner, finally, *Asserts* the consistent explanation, *Withdraws* the inconsistent one and following a further *Probe-construct* tactic completes the model by providing a consistent explanation for when 'person push is less than friction'. Thus, via a facilitating dialogue the learner refined an incomplete (i.e. excluding friction) and inconsistent (i.e. 'person push greater than friction causes box speed constant') explanatory model to form one that was complete and consistent for the context under discussion.

This example dialogue demonstrates how CoLLeGE implements the *f* dialogue-game and models the dialogue processes necessary for learning as knowledge refinement. Further examples showing how CoLLeGE simulated the tactics and tactic changes of an experienced

[V] Note: the system could explain that no net causal agent implies no change to property speed, compared with the inconsistent case where a net push has no effect, because effect of push is to increase speed.

tutor—addressing similar conceptual difficulties—and generalised this model are demonstrated in the next subsection.

Educational validation: does the model support belief revision and conceptual change?

An empirical study was undertaken, and has been reported in detail elsewhere (Ravenscroft, 1997, 2000). In this paper we will summarise the findings and demonstrate dialogue interactions that led to belief revision and improvements in explanatory performances that have been reported and show the dialogue modelling facilities offered by CoLLeGE.

Experimental Procedure

The chosen subject for the study was kinematics, and used the context of a person pushing a box or trolley along a (horizontal) floor—that was a context taken from previous research into conceptual change in science (Twigger et al., 1991). As we were validating our model, and the alternative conceptions that our dialogue-game is addressing have been shown to be prevalent in adults as well as students, we decided to use subjects with a range of education and experience. So those selected were deliberately diverse, including two pupils from a local school, three postgraduate students, one undergraduate and five adults engaged in various professions.

During the experimental sessions, the tutor asked the subjects to provide an initial explanation of the box or trolley pushing event and recorded their responses on a flip-chart. Following this the dialogue game was initiated. These dialogues were performed off-line, with the (human) tutor playing the facilitator role according to the specified framework—following the strategy and heuristics to make selections from the available tactics. Thus each student's initial naïve explanation—of what happened when the person pushed the box or trolley to get it moving, moved the object at a constant speed and then allowed it to come to a stop—was probed and critiqued in an inquiry manner. The aim was to elicit explanations that were more complete, consistent and general (couched in terms of the forces acting, including friction). This would lead to the student becoming more able to accurately predict what would happen in related scenarios, such as with a frictionless surface. The tutor documented the dialogue-game interchanges on the flip-chart according to the specified interaction language, and where necessary parsed the students natural language contributions into their equivalent interaction language representation. After each session these recorded dialogues were 'written up' as text files in a word processor.

Later, the experimenter[VI] used these records to enter the learners' utterances[VII] into the CoLLeGE system, so its tactics could be generated and compared against those selected by the tutor. In this way the system's ability to simulate the discourse was tested, with CoLLeGE tactics chosen from its preferential list. To examine the learning process, the experimenter checked the dialogues against the CoLLeGE inputs and outputs, noting conceptual difficulties and any differences, and assessed the explanatory models of the students as being consistent, complete and general in terms of the system's diagnostic criteria.

Between four and six weeks later a delayed post-test was given individually in which students answered written questions on the scenario. These written replies were then checked under the consistency, completeness, and generality criteria to examine whether the students' explanatory models had been retained.

[VI] The first author was "the experimenter".
[VII] Note that these are the utterances performed during the dialogue-game, the initial explanation of the event was not entered into CoLLeGE—as these were recorded for comparative purposes.

Summary of Dialogue and Test Performances

Accepting this is a small-scale study, all eleven students who participated showed, in varying degrees, deficient explanations and alternative conceptions in their initial narrative and explanatory accounts of the box or trolley pushing event. During the subsequent *f* dialogue-games eight students developed explanatory models of the event scenario that were complete and consistent, and which included the equilibrium condition under constant motion, with push and friction agents classified as forces. Five students were also able to generalise their explanations and specify them in terms of net force. Only three subjects could not be stimulated to revise their incomplete or inconsistent explanations, and how such students can be assisted is discussed briefly in the next section and elaborated in Ravenscroft (1997). The delayed post test data showed that the students (with one exception, S4) held to their revised and improved beliefs, shown in the dialogue sessions, neither improving nor regressing on their dialogue performances.

Simulating the dialogues: tactics and tactic changes

In simulating the dialogues we are validating the model by showing that those tactics selected by a tutor are generated in the repertoires made available by CoLLeGE, based on its reasoning about students' explanations. These simulations provide a powerful investigative framework since they make explicit in the discourse such pragmatic level features as type of move, dialogue tactic and the pedagogical goal addressed. This means that we can differentiate the same surface level features in terms of underlying pragmatic purpose and also record low-level tactical pedagogies (or plans) deployed during the dialogues (e.g. see Ravenscroft, 2000). The dialogue transcripts are lengthy (see Ravenscroft, 1997), so extracts from the CoLLeGE simulations will be used to demonstrate some of the interesting tactics and tactic changes which governed the flow and content of the dialogue.

The first extract demonstrates tactics that addressed a student's (S11) alternative conception of a push implying motion, which led to an impasse for the equilibrium condition when the trolley speed is constant. The student expressed this common but inconsistent assertion (in terms of the law of agency) 'push > friction causes trolley speed constant' (i.e. a net causal agent push resulting in no state change) in turn 19. This example contrasts nicely with the similar example in the previous subsection, because instead of 'entraping' the learner and forcing an immediate resolution, the tutor (and CoLLeGE) adopted a more subtle and less direct strategy. This time, in following the maxim of 'minimal exposition', a series of *Probe-construct* tactics were adopted that followed the 'prefer-opposite-value' heuristic to *Probe* the less than '< ' condition before the equilibrium '=' condition—see below:

19. S11. Push greater than friction causes the speed to be constant.
Assertion:- ASSERTION-32718
Abstract agent push > Abstract agent friction :causes
trolley has property speed. *Change:* constant

20. F. What is the consequence when push less than friction?
Goal:- CHECK-INFERRED-EQUILIBRATION-31036
Tactic:- **Probe-construct**
Construct: Abstract agent push < Abstract agent friction : causes ?

21. S11. Push less than friction causes the speed to decrease.
Assertion:- ASSERTION-36473
Abstract agent push < Abstract agent friction :causes
trolley has property speed. *Change:* decrease

22. F. What is the consequence when push equal to friction?
Goal:- CHECK-INFERRED-EQUILIBRATION-31032
Tactic:- **Probe-construct**
Construct: Abstract agent push = Abstract agent friction :causes ?

23. S11. Push equal to friction causes the speed to be constant.
Assertion:- ASSERTION-40224
Abstract agent push = Abstract agent friction : causes
trolley has property speed. *Change:* constant

Then, after probing for another explanation for when push is greater than friction and acquiring a consistent but contradictory explanation (ASSERTION-45223 below) the student was now asked to *Resolve* the explicit contradiction between this recent explanation and their previous one (ASSERTION-32718). They subsequently *Withdrew* the inconsistent assertion (32718), leaving a consistent explanatory model.

26. F. (Resolve Contradiction) same causes, different effects,
push greater than friction causes the speed constant,
push greater than friction causes the speed increase.
Goal:- ADDRESS-CAUSATION-VIOLATION-48838
Tactic:- **Resolve**
There is an explicit contradiction between ASSERTION-32718
ASSERTION-45223 (same agent, different effect)
Resolve:-
Assertion:- ASSERTION-32718
Abstract agent push > Abstract agent friction : causes
trolley has property speed. *Change*: constant
or
Assertion:- ASSERTION-45223
Abstract agent push > Abstract agent friction : causes
trolley has property speed. *Change*: increase

27. S11. Withdraw push greater than friction causes the speed constant
Statement **withdrawn** ASSERTION-32718

If these tactics prove unsuccessful—the *Persuade* tactic may be adopted, that was successful with another student (S7) who had the same alternative conception:

14. F. Push less than friction causes the trolley speed to decrease (a repeat of a student statement)
Isn’t it the case that a push equal to friction is a condition for trolley speed constant?
Goal:- ADDRESS-AGENCY-VIOLATION-62866
Tactic:- **Persuade**
In assertion ASSERTION-31238 you have given causal agent, no state change.
In Assertion:- ASSERTION-57992
Abstract agent push < Abstract agent friction : causes
trolley has property speed. *Change*: decrease
Isn't it the case that: Abstract agent push = Abstract agent friction :
is a condition for trolley has property speed. *Change*: constant

to which the student agreed, asserting;

15. S7. Push equal to friction condition for trolley speed constant.
Assertion:- ASSERTION-67244
Abstract agent push = Abstract agent friction : is a condition for
trolley has property speed. Change: constant

and then other inferences were probed.

Further tactics (shown with student S3) that were deployed to address the goal ACQUIRE-GENERAL-AGENT are *Acquire-construct* and *Probe-construct*, which deal with the difficulty of establishing an equilibrium condition when the push and friction effects have been established. This leads, hopefully, to the realisation that their effects can be 'added' to give a resultant equilibrium.

25. F. Is there a word which is general name for push and friction? Are they examples of the same type of thing?
Goal:- ACQUIRE-GENERAL-AGENT
Tactic:- **Acquire-construct**
Construct: Can you give a general name for push and friction?
Push AND friction ISA ?

26. S3. Yes...is it force?
Assertion:- push AND friction ISA force

27. F. So net push-force causes?
Goal:- CHECK-INFERRED-NET-RELATIONS
Tactic:- **Probe-construct**
Construct: Net push force causes ?

28. S3. Net push-force causes box speed increase.
Assertion:- Net push force causes box speed increase

29. F. Net friction-force causes?
Goal:- CHECK-INFERRED-NET-RELATIONS
Tactic:- **Probe-construct**
Construct: Net friction force causes ?

30. S3. Net friction-force causes box speed decrease.
Assertion:- Net friction force causes box speed decrease

31. F. Net force zero causes?
Goal:- CHECK-INFERRED-NET-RELATIONS
Tactic:- **Probe-construct**
Construct: Net force zero causes ?

32. S3. Net force zero causes box speed constant (no change).
Assertion:- Net force zero causes box speed constant

To summarise this latter interchange, once the *Acquire-construct* tactic had stimulated the learner to provide the General-agent 'force' as the generalisation of Abstract-agents 'push' and 'friction', following the 'prefer-net-General-agent' heuristic, a series of *Probe-construct* tactics acquired explanations for the net General-agents (i.e. 'push force' and 'friction force'). After which a further *Probe-construct* acquired an explanation for the zero-net General-agent condition (i.e. 'Net force zero'), facilitating the development of a complete, consistent and more general model for the motion context. In all these interactions (except for the occasional use of repetition) the CoLLeGE tactic preferences could be matched against those performed by the tutor, validating the implemented framework.

The simulations showed that CoLLeGE was successful in generating the tactics that were deployed by the tutor. Apart from the occasional use of repetition and the introduction of one refinement to an existing *Probe-construct* tactic, CoLLeGE was able to model the dialogues that were performed—allowing the interactions to be simulated and recorded in the CoLLeGE scheme. Further analysis has shown that these refinements were features of a low-level tactical pedagogy that was developed by the tutor—during the dialogue sessions—to address unforeseen conceptual difficulties experienced by the students (see Ravenscroft, 2000). This reflected a more subtle approach to tactic selection that operated within the specified dialogue game scheme (see below).

DISCUSSION AND FURTHER WORK

The validation studies described above demonstrate the potential of the approach. By adopting a dialogue modelling approach that focused on effective patterns of interaction and refining these within a Dialogue Game Theory paradigm to render them computationally tractable, the CoLLeGE approach was able to prompt belief revision and conceptual change in students—who developed more complete, consistent and general conceptual models for the physics of motion context. Moreover, those students who had difficulties could be assisted by allowing the system to become more ‘knowledgeable’. As students use CoLLeGE within specific contexts (e.g. kinematics) it will acquire the vocabulary and properties of the domain from the consistent and complete explanations contributed. Hence, it could be more wide ranging and interventionist in the contributions it makes, using hints or suggestions to introduce concepts such as ‘friction’ or ‘force’ when an impasse is reached. In short, the system could make stronger tutorial contributions when they are needed, following extended argumentation for example.

Currently, further work is proceeding in a number of directions. Firstly, the developed model is being evaluated more extensively, through empirical studies in schools. In these studies the *f* dialogue-game is being compared with conventional tutoring of the same topic and the significance of operating within a school context is being explored. Therefore, these studies will help us to make comparisons between our structured, collaborative argumentation model and more didactic approaches that incorporate natural asymmetric dialogue. Where the latter, in principle, can allow more freedom in student expression (e.g. they can ask questions, request confirmation of explanations, etc.), albeit within a more socially bounded student-teacher context.

As part of these studies the CoLLeGE work-bench is being used to further *investigate by design* the effectiveness of different dialogue strategies and tactics in supporting conceptual change and development in this context. Also, a more user friendly interface is under development that includes the pedagogic refinements to tactic selection that were identified during the validation study. It was noted that the tutor operated with a more subtle model of argument, that considered the semantics of the world model in conjunction with a record of what he had previously done *and* detailed (i.e. at the tactic level) plans about what he wanted to do in the future. Thus, further work will aim to model some features of this interplay between world model semantics and dialogue planning that takes account of the dialogue history. In brief, the implemented selection mechanisms will benefit from *learning* which tactics are most useful to help to decide when to deploy them. A further avenue for research and development is extending the framework towards the production of generic design tools aimed at providing future designers with a toolkit for investigating dialogue games to suit their own applications. This line of work is particularly interesting, because although we accept that our current CoLLeGE model is limited to qualitative causal domains, we argue that our methodology of investigation by design is not, and is in fact quite general. Our approach of formally rendering dialogue-games to design systems and pedagogical activities that can be systematically validated, evaluated and investigated can be applied to other types of dialogical interaction that are thought to be effective. For example we can use the work-bench system to explore the degree of symmetry or asymmetry in dialectical roles that best support learning in a variety of student contexts. Along these lines, current projects at the UK Open University are deploying this methodology to develop cognitive tools to support intelligent mediation of educational argumentation between distance learners participating in more discursive modes of dialogue and, model schoolchildren engaging in "exploratory talk" (Wegerif, 1996; Wegerif, Mercer & Dawes, 1999). These lines of work will marry on-going work on DISCOUNT with the modelling work described here.

SUMMARY AND CONCLUSIONS

We have proposed the methodology of 'investigation by design' for modelling effective educational dialogue and developed a dialogue-game framework and computer modelling work-bench for pedagogical argumentation within a collaborative context. Given the successful validation of this framework, from a computational and educational perspective, further work is developing the CoLLeGE system into a cognitive tool suitable for students and, evaluating and investigating the current model through empirical studies in schools. This research has demonstrated the value of linking a qualitative 'commonsense' reasoning model to dialogical tutoring strategies and tactics (e.g. *Challenge, Persuade, Resolve, Probe*) that are derived from empirical studies and tutoring practice. This approach has allowed us to model and maintain a facilitating argumentation dialogue that addresses pervasive conceptual difficulties experienced by students—in a domain where 'conventional' didactic teaching is known to have only limited success (Hartley, 1998). In addition, we have gained some insight into the subtleties involved in deciding when and how the particular dialogue tactics are deployed—and closer investigation of the successful patterns of interaction is the focus of current research. As we now have a clearer picture of the dialogue processes implicated in stimulating belief revision and new methodological tools for conducted further investigations, we expect the current projects to shed further light on the dialogue mechanisms that stimulate reasoning and conceptual change.

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