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Developing and evaluating dialogue games for collaborative e–learning

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Abstract This paper argues that developments in collaborative e-learning dialogue should be based on pedagogically sound principles of discourse, and therefore, by implication, there is a need to develop methodologies which transpose — typically informal — models of educational dialogue into cognitive tools that are suitable for students. A methodology of 'investigation by design' is described which has been used to design computer-based dialogue games supporting conceptual change and development in science — based on the findings of empirical studies. An evaluation of two dialogue games for collaborative interaction, a *facilitating* game and an *elicit-inform* game, has shown that they produce significant improvements in students conceptual understanding, and they are differentially successful — depending on the nature of the conceptual difficulties experienced by the learners. The implications this study has for the role of collaborative dialogue in learning and designing computer-based and computer–mediated collaborative interaction are discussed.

Keywords: Belief change; Collaboration; Dialogue; Empirical; Modelling; School; Science

Why develop models of collaborative dialogue?

Given the importance, and arguably the primacy, of dialogue in learning (e.g. Vygotsky, 1962, 1974), how can cognitive tools be designed that stimulate, support and mediate discourse processes that lead to conceptual development in collaborative e-learning contexts? Previous research has shown that a collaborative dialogue is often required to truly engage learners conceptualisations in ways that support the refinement of knowledge and improvements in understanding through tutor-led lines of reasoning (e.g. Pilkington & Parker-Jones, 1996; Hartley, 1998; Ravenscroft, 2000). These discourses, that resembled a Socratic dialogue in nature, have clearly demonstrated the role and relevance of pragmatic level — or contextual — dialogue features. These include the relative and changing — local — goals of the interlocutors, the asymmetrical roles that can be played, the use of particular types of speech act, or dialogue 'move' and the socially implicit 'rules of the dialogue game' (Ravenscroft & Pilkington, 2000). (It is accepted that, typically, the high level goal of a collaborative interaction, such as 'to achieve a mutual understanding or shared meaning' will usually be shared by participants. However,

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local discourse goals, such as 'to propose a complete explanatory model', 'to acquire a consistent explanatory model' or 'to generalise an explanatory model', will change during the progress of the dialogue, in order to achieve the higher level goals.) In contrast, many current dialogical approaches to computer-supported collaborative learning (CSCL), with a few exceptions such as C-CHENE (Baker *et al*., 1996) and BETTERBLETHER (Robertson *et al*., 1998), use generic 'off the shelf' computer-mediated communication (CMC) systems. Hence, these approaches tend to be technology-led, and take virtually no account of the importance of pragmatic level features (Ravenscroft, 2001). Instead, these systems operate as mere conduits of dialogue, and fail to provide the structure, management and guidance that is often necessary to support and mediate effective educational collaboration. Further, it has been noted that on-line tutors at the UK Open University and elsewhere consistently comment that using generic CMC systems is problematic. They point out that these systems often encourage educational discourse that is superficial (e.g. incoherent and with no agreed closure), ambiguous (e.g. lack of shared meanings and little appreciation of different points of view) or simply unmanageable (e.g. too many contributors and too much dialogue).

In addressing these problems, Ravenscroft & Pilkington (2000) proposed a systematic, yet technology independent, approach to interaction design that focuses on pragmatic level dialogue features. This is particularly suitable for designing types of computer-based and computer-mediated collaborative educational dialogue. The scheme incorporates dialogue game theory (Levin & Moore, 1977; MacKenzie, 1979; Walton, 1984) within a methodology of 'investigation by design' (IBD) that was developed by Ravenscroft & Pilkington (2000) to transpose — empirically derived — models of dialogue into collaborative discourse systems. The problem of transposing models of communicative interaction into usable educational technologies is a substantive issue in designing dialogical new media (Cook, 1998), because sound methodologies for achieving this, other than the one proposed, simply don't exist.

A methodology: investigation by design

The 'investigation by design' (IBD) methodology takes a direct approach to the transposition problem. It incorporates a discourse analysis scheme called DISCOUNT (Pilkington, 1999) — that was developed by synthesising features of dialogue game theory (Levin & Moore, 1977; Walton, 1984), transactional analysis (Stubbs, 1983; Sinclair & Coulthard, 1992) and rhetorical structure theory (Meyer, 1975) — to classify the relevant features of successful dialogue. Here, 'successful dialogue' refers to that which avoids some of the pitfalls of freer on-line or natural discourse, that were described in the section above, or has accepted efficacy in achieving context related goals, such as 'collaborative argumentation' (Ravenscroft & Hartley, 1999; Ravenscroft, 2000), 'exploratory talk' (Wegerif, 1996) and 'constructive conflict' (Kuhn *et al.* 1997). Within the IBD scheme, the characteristics classified by DISCOUNT are then abstracted into a semi-natural set of dialogue features. These include participant goals (e.g. elaboration of knowledge, coelaboration of knowledge, articulating and winning an argument), participant roles (e.g. explainer, inquirer, critiquer, proponent, opponent), dialogue tactics or moves (e.g. assertion, agree, challenge, persuade, withdraw) along with the rules that guide and manage the interaction. These features are then designed as explicit components of a dialogue game — that in this case is an operational model which is built from these identified features. This dialogue model is then formally rendered to produce a system implementation.

Previous research has applied this methodology to produce an intelligent computer-based argumentation system called CoLLeGE (Computer-based Laboratory for Language Games in Education) that has been reported by Ravenscroft (1997) and Ravenscroft & Pilkington (2000). Other projects have used dialogue games to implement a computer-mediated argumentation system called DIALAB (Pilkington *et al.*, 1992) and a computer modelling laboratory for investigating collaboration called CLARISSA (Burton et al., 2000).

The strength of this IBD approach rests in its pedagogical fidelity and flexibility. Other dialogue game approaches to interaction design (e.g. Moore, 1993, 2000; Moore & Hobbs, 1996; Maudet & Evrard, 1998) usually take an existing dialogue model, such as the DC dialogue game (Mackenzie, 1979) — for fair, reasonable and competitive debate, and test their applicability in educational discourse contexts. Instead, the IBD approach constructs models based on empirical evidence of successful dialogue in a particular context. It uses the features of descriptive (e.g. Levin & Moore, 1977) and prescriptive (e.g. MacKenzie, 1979; Walton, 1984) dialogue game theory — included in the DISCOUNT Scheme — as 'building blocks' for specifying the models. In specifying new dialogue games, the features of existing models are re-used, developed and synthesised. It is suggested that the rigorous and systematic nature of this approach explains the successful operation of the delivered dialogue games — in supporting conceptual change and development — that has been found in empirical studies reported in Hartley & Ravenscroft (1999) and Ravenscroft (2000).

Two dialogue games for collaborative interaction

Two models of collaborative inquiry dialogue to support conceptual change and development in science were developed using the IBD methodology. The models are specified as dialogue games involving a tutor-system and learner participant. One model is a *facilitating* dialogue game (hereafter *f-dg*) for collaborative argumentation. The other is an *elicit-inform* game (hereafter *ei-dg*), that supports a collaborative discourse that is similar in many respects to the *f-dg*, but includes some didactic features. The latter was developed to address and investigate limitations in the former that were suggested by empirical studies (Hartley & Ravenscroft, 1999; Ravenscroft, 2000).

A motivation for developing different models, with similar and dissimilar features, is that the effectiveness of each model can be compared through systematically varying the use of certain discourse features — such as the type of tutoring tactic, whilst keeping other features constant, such as the tutor-system reasoning and dialogue strategy. This allows the establishment and examination of the particular features that make collaborative dialogue successful in relevant contexts.

A facilitating dialogue game

The *facilitating* dialogue game (*f-dg*) supports a discourse that is a form of collaborative argumentation (Ravenscroft, 2000), which was shown to be necessary to support conceptual change and development in science (Twigger *et al.*, 1991; Hartley, 1998). Within this game, the student is *questioned* and encouraged to express their understanding of a domain and to refine this in response to the tutor-system reasoning about the learner's explanations — examining their completeness, consistency and generality — and consequently *challenging*, *critiquing*, and *probing* the student's explanatory model. A significant feature of this game is that the student cannot be informed of the appropriate answer. Instead, the qualitative 'logic' of the domain, or 'illogic' of the student's explanations, is reflected back to them in ways that encourage the identification of incompleteness or inconsistencies in their model, stimulating the student to refine their model for themselves. So learners are stimulated to integrate concepts that are commonly held and already 'in their heads' (e.g. friction, force, motion) into improved conceptual schema — that accord with curriculum science (e.g. Newton's laws of motion). Similarly, to refine incorrect alternative conceptions (e.g. that force implies motion) into ones that are more complete, consistent and general — which accord with the scientific view (e.g. a net force implies a change in motion).

This game is typically conducted for up to 45 minutes, where the duration depends on how successful the student is in developing a complete, consistent and general model. It is described in detail, with appropriate examples, in Ravenscroft (1997) and Ravenscroft & Pilkington (2000). This model has already been partially validated through a small-scale study in a laboratory context, which showed that it was educationally effective (Ravenscroft, 2000) and computationally tractable (Ravenscroft & Pilkington, 2000). So, a larger-scale evaluation 'in the field' was planned to examine its effectiveness on the context of the school curriculum. Findings from the initial studies, that demonstrated a requirement to be more 'informing' than 'facilitating' on some occasions, gave rise to a modified version of this game. This was the *elicit-inform* game that was also evaluated in the reported study and is described below.

An elicit-inform dialogue game

The empirical studies validating the *f-dg* demonstrated that a purely facilitating pedagogy, whilst technically attractive, as it avoids the necessity for a sophisticated and detailed domain model, would benefit from some additional tactics that were more didactic in nature. Therefore, the *f-dg* was modified to develop an *elicit-inform* game (*ei-dg*). In this case the student is *questioned* and encouraged to express their understanding of a domain — as in the *f-dg*. But, after reasoning about the learner's contributions, the tutor-system either *sanctions* their explanations by informing them that they were correct, or points out that they were 'incorrect' and so *informs* them of a consistent, or 'correct' answer — hence, introducing new concepts where necessary. So, this tutor-system follows the same strategy as in the *f-dg*, based on the same reasoning, but uses different tactics to address incompleteness and inconsistencies in the learner's explanatory model.

This game is typically conducted for about 20 minutes, and is reported in detail, with appropriate examples, in Matheson & Ravenscroft (2001).

Evaluating the dialogue games

An empirical study evaluated these dialogue games in the context of a school physics curriculum. The evaluation focussed on the topic of 'forces and motion'. This topic was chosen because it had been shown that a collaborative and dialectical tutoring dialogue, that was analogous to the *f-dg*, was necessary to support students in developing an improved conceptual understanding of this domain (Hartley, 1998). More specifically, it has been shown that this type of discourse was needed to assist students in overcoming pervasive alternative conceptions, such as 'a force implies motion' (Clement, 1982; Gunstone & Watts, 1986) in order to develop a more complete, consistent and general conceptual understanding of this topic (Hartley & Ravenscroft, 1999; Ravenscroft, 2000).

Method

Subjects

Thirty-six subjects participated in the study. All were pupils in Year 11 of a UK secondary school and were aged between 15 and 16 years. They were all studying science and had been taught the relevant topic as part of their normal classroom teaching. None of the subjects had any previous knowledge of the research.

Materials

The subjects were provided with paper and a pen with which to record their explanations, that were elicited during a pre-, post- and delayed post-test (see below). The facilitator documented the dialogues on a flip-chart, and each session was also recorded on video.

Design and procedure

The relative effectiveness of the *f-dg* and *ei-dg* was evaluated by comparing them with a control group that received only the conventional teaching — as per previous lessons and exercises in the school. A researcher performed the tutor-system role in both games. Twelve students were assigned to each of the three conditions. The sessions began with the researcher introducing a hypothetical scenario to the subject: '*Consider the example of a person pushing a box, they get it moving and push it for a bit and then stop pushing*'. The subject was then asked to explain what happens to the box and what causes the changes, to elicit their initial explanatory model. A pre-test was then administered. This consisted of seven questions concerning the box-pushing scenario. The questionnaire was contingent in that while all the subjects were asked Questions 1, 2 and 3 the subjects were only asked any further questions if they had introduced the appropriate concepts (i.e. a pushing force and friction). This was done in order to avoid introducing new concepts to the subjects. The first three questions were, respectively, *what causes the box speed to increase/decrease/remain constant?* Questions 4, 5 and 6 were *what is the relationship between push and friction when the box speed increases/remains constant/decreases?* Question 7 asked subjects *whether push and friction were the same type of thing, and if so what they were*.

Following the pre-test, depending upon the condition, the subjects either participated in the *f-dg*, or the *ei-dg*, or, in the case of the control condition, they received some teaching on an unrelated topic. These in turn were followed by a post-test consisting of the same questions as the pre-test. Approximately six weeks after the initial testing the subjects were given a delayed post-test, that was identical to the pre- and post-tests.

Results

Table 1 shows the means and standard deviations for the improvements in students explanations — in line with the appropriate physics — between pre- and post-test, and between pre- and delayed post-test.

Table 1. Means and standard deviations for each condition between pre and post-test, and between pre and delayed post-test.

	f-dg		***ei-dg***		**Control**	
	m	***sd***	***m***	***sd***	***m***	***sd***
Post – Pre-	2.92	2.3	2.08	2.58	0	0.17
Delayed – Pre-	2.83	2.2	2.58	2.19	0.75	1.85

The results of a quantitative analysis of all seven of the questions in the pre-, post- and delayed post-tests showed that the introduction of the dialogue games produced significant improvements in the students' knowledge of the topic compared with conventional teaching alone ($F_{2,23} = 7.97$, $p < 0.05$), with these improvements in the students' explanatory models being retained in the delayed post tests ($F_{2,23} = 3.32$, $p < 0.05$). Post hoc analysis showed there was a significant difference between the *f-dg* and control condition and a significant difference between *ei-dg* and control condition at post-test and delayed post-test.

Chi square analyses — of responses to question number 2 that was designed to elicit friction — showed that both dialogue games produced significant improvements in stimulating the students to develop a more complete understanding, by introducing friction into their explanatory models (*f-dg*: $\chi^2 = 6.1$, d.f. = 1, $p < 0.05$; *ei-dg*: $\chi^2 = 10.3$, d.f. = 1, $p < 0.05$), with a slightly larger improvement being noted for the *ei-dg* condition (see Matheson & Ravenscroft, 2001).

An analysis of responses to Questions 3 and 5 of the tests, that elicited known alternative conceptions related to forces and motion, showed that there were significant differences between conditions between pre- to post-test ($F_{2,33} = 5.39$, $p < 0.05$) and pre- to delayed post-test ($F_{2,33} = 3.32$, $p < 0.05$). Post hoc analysis showed that there was a significant difference between each of the two dialogue game conditions and the control condition between pre- and post-test and a significant difference between the *f-dg* and the control condition at delayed post-test.

It was interesting that all students had difficulty in generalising their models by expressing them in terms of 'net forces', because they did not understand the concept of 'net' and, for this reason, the dialogue games were shorter in duration than was anticipated, being conducted for up to 30 minutes.

Discussion

These results clearly demonstrate the effectiveness of both dialogue games in stimulating improvements in the students' understanding of the physics of motion. It was also noted that the dialogue games worked differentially in addressing the conceptual difficulties experienced by students. The *f-dg* was more effective in addressing alternative conceptions about the context, such as 'force implies motion'. Whereas the *ei-dg* appeared slightly more effective in addressing incompleteness in the students' models, such as the exclusion of friction. The difficulties that the students experienced with the concept of 'net' and consequently 'net force' accords with previous findings reported by Hartley & Ravenscroft (1999).

A detailed qualitative analysis of the initial explanatory models and interventions is being conducted, to establish and examine what particular tutoring tactics, patterns of tactics and structural features of interchanges account for the findings reported above.

The outcomes of this research have implications for the role of collaborative dialogue in learning and designing CSCL interactions. Taking the results of the evaluation study collectively, a striking finding is that the addition of up to 30 minutes of a stylized collaborative inquiry dialogue about a topic produces significant improvements in students' knowledge and conceptual understanding compared with 'conventional' teaching alone. A more argumentative dialogue, employing *challenge*, *persuade* and *resolve* tactics to 'reflect back' the underlying logic, and the students' 'illogic', appears necessary to address pervasive alternative conceptions experienced by students. Whereas *informing*, within a collaborative dialogue context, may be necessary to introduce the key concepts that students need to integrate into their conceptualisations in order to develop a more complete and logically consistent model.

The positive nature of findings from the evaluation vindicates using the dialogue models as the basis for designing intelligent tutoring agents and interfaces for CSCL. In the first case, all of the features of the dialogue models — the dialogue moves, tutor-system reasoning, dialogue strategy and (template-based) language recognition and generation components are implemented in the CoLLeGE system[†], that is described in Ravenscroft & Pilkington (2000). This system is currently being developed into a 'facilitating tutor' for collaborative argumentation. In the second case, the dialogue tactics and moves are implemented in an interface to support structured computer-mediated collaboration. For example, McAlister (2001) is developing a web–based interface supporting dialectical discussion about controversial subjects. With regard to the problem of conceptual change and development in science, the results suggest improving the *f-dg* dialogue by including the key concepts for the domain, such as 'force' or 'friction', using *inform* moves to communicate these concepts to the learner in cases where they have an incomplete model.

The methodology reported in this paper is important because it addresses the need for a 'science' of learning technology design, which incorporates an *implementation independent 'design level'*. This is an important advantage of current dialogue game approaches. Given that the pace of change of underpinning technology is unlikely to slow down, the need for relatively more stable and empirically founded interaction models is becoming increasingly important. This and other studies have shown that these dialogue models can be developed and tested systematically, irrespective of technological changes and trends.

In arguing for the above, the aim is a much closer fit between empirical research, design, implementation and evaluation in educational technology research and development, that has direct implications for designing tools supporting CSCL. One way to interpret this emphasis on empirically founded and testable dialogue models is that the approach is treating *'design as theory'* (Ravenscroft, 2001). The research is considering pedagogy, technology and dialogue context in the design of

[†] The language recognition and generation components of CoLLeGE currently use a specially designed 'interaction language' (see Ravenscroft & Pilkington, 2000) that obviates the need for sophisticated mechanisms for natural language understanding and generation.

educational interactions, in ways that treat designs, like theories, as something that are developed, evaluated and refined — rather than ‘delivered’. The dialogue models are also prescriptive, so predictions about the impact on learner knowledge and behaviour can be made before and during the evaluation of implemented systems, rather than just ‘trying the system out and seeing what happens’. Additionally, the approach accepts that a design does not automatically generalise across contexts, but instead, can be evaluated and systematically developed to address different situations. Given that there will be identifiable ‘family resemblance’s’ (Wittgenstein, 1953) between collaborative dialogue contexts, it is argued that this is an economical way to achieve high quality educational interactions.

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