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# IEL-BASED FORMAL DIALOGUE SYSTEM FOR TUTORIALS

**Abstract.** Formal dialogue system for tutorials $\mathrm{DL(IEL)_T}$ is introduced. The system allows for modelling certain behaviours related to questioning agendas observed in tutorial dialogues. Inferential Erotetic Logic is the underlying logic of questions used here. Tutorial dialogues retrieved from the Basic Electricity and Electronics Corpus are presented and analysed with the use of $\mathrm{DL(IEL)_T}$.

**Keywords**: questions; tutorials; inferential erotetic logic; erotetic implication; erotetic search scenario

## Introduction

In this paper I present a formal dialogue system with underlying concepts of erotetic inferences validity taken from Inferential Erotetic Logic (hereafter IEL). The aim of this system is to model certain behaviours related to the use of questioning agendas, that may be observed in tutorial dialogues. IEL [28, 33] is a logic which focuses on inferences whose premises and/or conclusion is a question, and which gives criteria of validity of such inferences. Thus it offers a very useful and intuitive framework for analyses of the questioning process and it is a natural point of departure for the proposed approach. The dialogue logic overlay is used here in order to grasp linguistic phenomena and dialogue behaviours in a precise manner. The motivation for such an approach is twofold. Firstly, it comes from the system presented in [16, 17], where a dynamic epistemic component is added to a logic of questions in order to describe an information seeking procedure. The key difference is that I

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will not use dynamic epistemic logic for my purposes, but dialogue logic inspired by Girle's DL systems [3]. Analysing a dialogue in terms of commitment stores allows for a simpler and more intuitive description of the dialogue events. What is important is that I take into account information expressed in a dialogue. In the presented framework I do not hypothesise about all the knowledge that is at the agents' disposal. Such an approach is convincing when we think of modelling natural language dialogues and also for systems of formal dialogues. Secondly, my approach shares the main intuition with systems presented in [1, 7], namely of using a logic in the background of a formal dialogue system in order to check the correctness of certain dialogue moves.

I propose such an approach in [12, Chapter 4], where it is applied to information seeking dialogues in general. There I introduce $\mathrm{DL(IEL)}_2$ and $\mathrm{DL(IEL)}_{\mathrm{mult}}$ systems which allow for modelling verbal behaviours of an information seeking agent using an erotetic search scenario (a tool developed within IEL) as a questioning strategy in the context of a two- and multi-agent dialogues. In [12] I also introduce two systems of this type for a generation of cooperative dialogical behaviours: $\mathrm{DL(IEL)}_{\mathrm{COOP1}}$ and $\mathrm{DL(IEL)}_{\mathrm{COOP2}}$. In this paper the general approach will be applied to the tutorial dialogues domain.

I am especially interested in the way questions may be used by a tutor in a tutorial dialogue.[1] As we may read in [27, p. 1]: "A tutor often faces the decision of whether to just tell the student an explanation or to try to elicit the explanation from the student via a series of questions." The most natural way of thinking about such a questioning process is that a tutor will have certain agenda of questioning, which will allow for checking, whether a student really understands an issue under discussion.

In what follows I will use natural language examples retrieved from The Basic Electricity and Electronics Corpus (BEE) [19], which consists of tutorial dialogues from electronics courses. The corpus search was done using using the SCoRE software [18]. I preserve the original spelling in all the examples.

Let us consider an example which illustrates behaviours that will be of my interest in this paper.

*Example* 1. TUTOR: No, you don't have to hook the leads directly to the battery. The important thing is that you observe polarity.

[1] More discussion on question types and question dependencies in the more general context of information seeking dialogues may be found in [13] and [12, Chapter 3].

Do you know what the rule for observing polarity is?

STUDENT: yes I do

TUTOR: Can you tell me?

STUDENT: It's when the positive end of the meter is connected to the positive end of the circuit and the same for the negative end

TUTOR: Right, but do you know how to determine what is the positive side of the circuit and what is the negative side? If the red lead were hooked up to tab #2, which tab positions would be included in the negative side of the circuit? [*BEE(F), stud46*][2]

In the presented fragment tutor (hereafter T) wants to know whether student (S) knows the rule for observing polarity. T receives a declaration that S knows the rule. However, it is not enough for T, thus he decides to ask auxiliary questions that will check, whether S knows and — what is important — understands the rule. As we will observe in other examples presented further in this paper (and as it is intuitive for anyone who ever tried teaching) there are cases when T will not reveal the first (initial) question, but instead he will develop an agenda of questioning. Answers gathered to auxiliary questions allow him to decide whether S knows/understands a given issue. At this point it is worth to stress that I will not consider cases when S asks questions. I discuss this issue in the summary.

When it comes to answers provided by S, I will focus on their interpretation by T. Certainly, in a tutorial context, while asking a question, T expects certain answer, or to put it in other words, expect a certain answer, which he will accept (see e.g. tutor's 'Right' and 'Good' in the last turns of Examples 1 and 3). There may be also answers that T will interpret as wrong ones or not acceptable in a given context, as in Example 2 ('Not quite').

*Example* 2. TUTOR: Right, and what does the third band stand for?

STUDENT: SO, 601

TUTOR: Not quite. The third band stands for how many zeros you add to the end. [*BEE(P), stud1*]

However, for the teaching context we should also consider cases where S's answer would fail into neither category. These may be simply 'I don't

[2]This notation indicates BEE sub-corpus (P: Pilot Study; F: Final Experiment) and the file number (stud46). Unfortunately no sentence numbering is available for the BEE corpus.

know' answer as in Example 3 (student's first and second turn) or S answer which may be interpreted as such, like in Example 4.

*Example* 3. TUTOR: Can you tell me how current would flow? Would it flow only through the wire? Or only through the meter? Or through both? Or through neither?

STUDENT: I don't know.

TUTOR: Is there any reason why it wouldn't flow through the wire?

STUDENT: I don't know.
Would the leads prevent or obstruct it in some way?

TUTOR: No.
If you know that the leads do not obstruct the current flow in any way, can you answer my question?

STUDENT: I guess I'd have to say yes. The current would flow through both.

TUTOR: Good. [*BEE(F), stud48*]

*Example* 4. TUTOR: You are on the right track. The battery is the source. But the lightbulb is not the source, it is the load. Do you know what the load does in the circuit?

STUDENT: no

TUTOR: First off, you need to understand that the source is really the voltage source, not the current source. [*BEE(F), stud47*]

The formal dialogue system presented here uses erotetic search scenario to capture the idea behind an agenda of questioning for tutor. I also use a language which allows for expressing questions with three possible answers ('yes', 'no', 'I do not know'), to cover the possible lacks of knowledge. Dialogue logic overlay enables expressing the dynamics of information exchange in a dialogue. The outline of the paper is the following. Next section contains the IEL basics, including the formalisation of questions, erotetic implication and erotetic search scenario. Section 2 discusses how erotetic search scenarios may be used to represent questioning agendas. In Section 3 I introduce the system $\mathrm{DL(IEL)_T}$ by presenting locution types, interaction rules and commitment store rules. I also present examples of a tutorial dialogues modelled in $\mathrm{DL(IEL)_T}$.

## 1. Erotetic inferences and search scenarios

After [9] I will introduce the formal language $\mathcal{L}^?_{\mathbf{K}3}$, which will be used further on in this paper. The language allows to express questions with three possible answers: 'yes', 'no' or 'I don't know'. For my purposes I will use Kleene's strong three-valued logic **K**3 (see [26]). As the starting point we take the language $\mathcal{L}_{\mathbf{K}3}$. The language contains the following primitive connectives: $\neg$ (negation), $\rightarrow$ (implication), $\vee$ (disjunction), $\wedge$ (conjunction), $\leftrightarrow$ (equivalence). The concept of a *well-formed formula* (wff for short) is defined in a traditional manner. We use $p$, $q$, $r$, $s$, $p_1$, ..., for propositional variables. Valuation ($v$) is understood in a standard way. The connectives are defined by the following truth-tables:

| | $\neg$ |
|---|---|
| 1 | 0 |
| $1/2$ | $1/2$ |
| 0 | 1 |

| $\wedge$ | 1 | $1/2$ | 0 |
|---|---|---|---|
| 1 | 1 | $1/2$ | 0 |
| $1/2$ | $1/2$ | $1/2$ | 0 |
| 0 | 0 | 0 | 0 |

| $\vee$ | 1 | $1/2$ | 0 |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| $1/2$ | 1 | $1/2$ | $1/2$ |
| 0 | 1 | $1/2$ | 0 |

| $\rightarrow$ | 1 | $1/2$ | 0 |
|---|---|---|---|
| 1 | 1 | $1/2$ | 0 |
| $1/2$ | 1 | $1/2$ | $1/2$ |
| 0 | 1 | 1 | 1 |

| $\leftrightarrow$ | 1 | $1/2$ | 0 |
|---|---|---|---|
| 1 | 1 | $1/2$ | 0 |
| $1/2$ | $1/2$ | $1/2$ | $1/2$ |
| 0 | 0 | $1/2$ | 1 |

The language $\mathcal{L}_{\mathbf{K}3}$ is also augmented with two additional unary connectives $\boxminus$ and $\boxplus$. It should be stressed that the new connectives never occur inside the wffs of $\mathcal{L}_{\mathbf{K}3}$ and they cannot be iterated.

The intended reading of the new connectives is the following:

- $\boxminus A$ — an agent *cannot* decide if it is the case that $A$ using his/her knowledge.
- $\boxplus A$ — an agent *can* decide if it is the case that $A$ using his/her knowledge.

The connectives are characterised by the following truth-table:

| $A$ | $\boxminus A$ | $\boxplus A$ |
|---|---|---|
| 1 | 0 | 1 |
| $1/2$ | 1 | 0 |
| 0 | 0 | 1 |

In the next step we will define language $\mathcal{L}^?_{\mathbf{K}3}$, built upon $\mathcal{L}_{\mathbf{K}3}$, in which questions may be formed. The vocabulary of $\mathcal{L}^?_{\mathbf{K}3}$ contains the vocabulary of $\mathcal{L}_{\mathbf{K}3}$ (thus also the connectives $\boxplus$, $\boxminus$) and the signs: ?,{,}.

Questions of $\mathcal{L}^?_{\mathbf{K3}}$ are expressions of the form:

$$?\{A_1, \ldots, A_n\},$$

where $n > 1$ and $A_1, \ldots, A_n$ are nonequiform (i.e., pairwise syntactically distinct) declarative well-formed formulas of $\mathcal{L}_{\mathbf{K3}}$. If $?\{A_1, \ldots, A_n\}$ is a question, then each of the d-wffs $A_1, \ldots, A_n$ is called a *direct answer* to the question.[3] If $Q$ is a question of $\mathcal{L}^?_{\mathbf{K3}}$, then $\mathbf{d}Q$ denotes the set of direct answers to $Q$.

We are interested in a specific category of *ternary* questions, which may be viewed as the counterparts of simple yes-no questions, provided with the third possible answer "it is not known whether". Thus a ternary question will be represented in language $\mathcal{L}^?_{\mathbf{K3}}$ as follows:

$$?\{A, \neg A, \boxminus A\}.$$

In what follows I adapt the following notation:

$$? \pm \boxminus |A, B|$$

refers to a question of the form:

$$?\{A \wedge B, A \wedge \neg B, A \wedge \boxminus B, \neg A \wedge B, \neg A \wedge \neg B,$$
$$\neg A \wedge \boxminus B, \boxminus A \wedge B, \boxminus A \wedge \neg B, \boxminus A \wedge \boxminus B\}.$$

It is a ternary counterpart of binary conjunctive questions (see [23]).

### 1.1. Erotetic implication

In IEL erotetic inferences of two kinds are analysed:

- *Erotetic inferences of the first kind*, where a set of premises consists of declarative sentence(s) only, and an agent passes from it to a question — grasped under the notion of *question evocation* (see [33, Chapter 6]).
- *Erotetic inferences of the second kind*, where a set of premises consists of a question and possibly some declarative sentence(s) and an agent passes from it to another question — grasped under the notion of *erotetic implication*.

[3] This approach employs the so called set-of-answers methodology (see [6]; [14, 15] and discussion in [33, pp. 16–18]).

In this paper I will be interested only in the erotetic inferences of the second kind. Erotetic implication (e-implication) is a semantic relation between a question, $Q$, a (possibly empty) set of declarative well-formed formulas, $X$, and a question, $Q_1$. It is an ordered triple $\langle Q, X, Q_1 \rangle$, where $Q$ is called an *interrogative premise* or simply *initial question*, the elements of $X$ are *declarative premises* and the question $Q_1$ is the *conclusion* or the *implied question* — see [33, pp. 51–52].

The intuition behind e-implication might be expressed as follows. Let us imagine an agent who is trying to solve a certain (possibly) complex problem. The problem is expressed by her initial question ($Q$). We assume that the agent does not have resources to answer the initial question on her own. Thus the initial question has to be processed/decomposed. This decomposition is aimed at replacing the initial question with a simpler auxiliary question — $Q_1$. The auxiliary question obtained as a result of the decomposition process should have certain characteristics. First of all, it should stay on the main topic. In other words, no random questions should appear here. However, the main characteristic that we are aiming at is that the answer provided to the auxiliary question should be at least a partial answer to the initial question (i.e., it should narrow down the set of direct answers to the initial question, see [33, p. 43]). It should bring our agent closer to solving the initial problem. Summing up, we can perceive the discussed process of replacing one question with another (simpler) one as a well-motivated step from the problem-solving perspective and the concept of e-implication as a formal counterpart of that process.

Before I provide a formal definition of e-implication I will introduce the necessary concepts.[4] The basic semantic notion to be used here is that of a *partition* (see [33, pp. 25–30]).

Definition 1 (Partition of $\mathcal{L}_{\mathbf{K}3}$). [9, p. 61] Let $\mathcal{D}_{\mathcal{L}^?_{\mathbf{K}3}}$ be the set of declarative well-formed formulas of language $\mathcal{L}^?_{\mathbf{K}3}$. By a *partition of language* $\mathcal{L}^?_{\mathbf{K}3}$ we mean an ordered pair $\mathsf{P} = \langle \mathsf{T}_\mathsf{P}, \mathsf{U}_\mathsf{P} \rangle$ such that:

- $\mathsf{T}_\mathsf{P} \cap \mathsf{U}_\mathsf{P} = \emptyset$
- $\mathsf{T}_\mathsf{P} \cup \mathsf{U}_\mathsf{P} = \mathcal{D}_{\mathcal{L}^?_{\mathbf{K}3}}$

[4] IEL introduces a series of semantic concepts about questions. Semantics for questions are provided by the means of the so called Minimal Erotetic Semantics (MiES) — for more details see [33, Chapter 4]. It is worth stressing that MiES enables for enriching any formal language with questions, provided that this language allows for partitioning declarative formulas into true and untrue ones (cf. [29, 30, 33]).

By a *partition of the set* $\mathcal{D}_{\mathcal{L}^?_{\mathbf{K}3}}$ we mean a partition of language $\mathcal{L}^?_{\mathbf{K}3}$. If for a certain partition $\mathsf{P}$ and a d-wff $A$, $A \in \mathsf{T_P}$, then we say that $A$ is *true in* $\mathsf{P}$, otherwise, $A$ is *untrue in* $\mathsf{P}$. What is essential for the semantics of $\mathcal{L}^?_{\mathbf{K}3}$ is the notion of a $\mathbf{K}3$-admissible partition. First, we define the notion of a $\mathbf{K}3$-*assignment* as a function $VAR \longrightarrow \{0, \frac{1}{2}, 1\}$. Next, we extend $\mathbf{K}3$-assignments to $\mathbf{K}3$-*valuations* according to the truth-tables of $\mathbf{K}3$. Now we are ready to present (see [9, p. 61]):

Definition 2 (Admissible partition of $\mathcal{L}_{\mathbf{K}3}$). We will say that partition $\mathsf{P}$ is $\mathbf{K}3$-*admissible* provided that for a $\mathbf{K}3$-valuation $V$, the set $\mathsf{T_P}$ consists of formulas true under $V$ and the set $\mathsf{U_P}$ consists of formulas which are not true under $V$.

We can now introduce the notions of sound and safe questions.

Definition 3 (Soundness). A question $Q$ is called *sound under a partition* $\mathsf{P}$ provided that some direct answer to $Q$ is true in $\mathsf{P}$.

Definition 4 (Safety). We will call a question $Q$ *safe*, if $Q$ is sound under each $\mathbf{K}3$-admissible partition.

We will make use of the notion of a multiple-conclusion entailment (see [20], see also [21]), which denotes a relation between sets of declarative well-formed formulas generalising the standard relation of entailment.

Definition 5 (Multiple-conclusion entailment in $\mathcal{L}^?_{\mathbf{K}3}$). [9, p. 62] Let $X$ and $Y$ be sets of declarative well-formed formulas of language $\mathcal{L}^?_{\mathbf{K}3}$. We say that $X$ *mc-entails* $Y$ in $\mathcal{L}^?_{\mathbf{K}3}$, in symbols $X \Vdash_{\mathcal{L}^?_{\mathbf{K}3}} Y$, iff there is no $\mathbf{K}3$-admissible partition $\mathsf{P} = \langle \mathsf{T_P}, \mathsf{U_P} \rangle$ of $\mathcal{L}^?_{\mathbf{K}3}$ such that $X \subseteq \mathsf{T_P}$ and $Y \subseteq \mathsf{U_P}$.

Now we are ready to introduce the notion of erotetic implication in $\mathcal{L}^?_{\mathbf{K}3}$ (see [9, p. 62]).

Definition 6 (Erotetic implication in $\mathcal{L}^?_{\mathbf{K}3}$). Let $Q$ and $Q^*$ stand for questions of $\mathcal{L}^?_{\mathbf{K}3}$ and let $X$ be a set of d-wffs of $\mathcal{L}^?_{\mathbf{K}3}$. We will say that $Q$ $\mathcal{L}^?_{\mathbf{K}3}$-*implies* $Q^*$ *on the basis of* $X$, in symbols $\mathbf{Im}_{\mathcal{L}^?_{\mathbf{K}3}}(Q, X, Q^*)$, iff

1. for each $A \in \mathbf{d}Q$, $X \cup \{A\} \Vdash_{\mathcal{L}^?_{\mathbf{K}3}} \mathbf{d}Q^*$, and
2. for each $B \in \mathbf{d}Q^*$, there is a non-empty proper subset $Y$ of $\mathbf{d}Q$ such that $X \cup \{B\} \Vdash_{\mathcal{L}^?_{\mathbf{K}3}} Y$.

The first clause of the above definition warrants the *transmission of soundness* (of the implying question $Q$) *and truth* (of the declarative premises in $X$) *into soundness* (of the implied question $Q^*$). The second clause expresses the property of "open-minded cognitive usefulness" of e-implication, that is, the fact that each answer to the implied question $Q^*$ narrows down the set of direct answers to the implying question $Q$.

Let us consider examples of e-implication in $\mathcal{L}^?_{\mathbf{K3}}$ (more examples may be found in [9]).

$$\mathsf{Im}(?\{A \wedge B, \neg(A \wedge B), \boxminus(A \wedge B)\}, ? \pm \boxminus|A, B|),$$
$$\mathsf{Im}(? \pm \boxminus|A, B|, ?\{A, \neg A, \boxminus A\}),$$
$$\mathsf{Im}(?\{A \vee B, \neg(A \vee B), \boxminus(A \vee B)\}, ? \pm \boxminus|A, B|),$$
$$\mathsf{Im}(?\{A, \neg A, \boxminus A\}, \{A \leftrightarrow B \wedge C, \boxminus B\}, ?\{C, \neg C, \boxminus C\}).$$

### 1.2. Erotetic search scenarios

When we think about e-implication used for decomposing questions as described above it is easy to imagine that it might be repetitively applied while solving a particular complex problem. The intuition behind such a process is perfectly grasped under [33, p. 103]:

**EDP** (*Erotetic Decomposition Principle*) Transform a principal question into auxiliary questions in such a way that: (a) consecutive auxiliary questions are dependent upon the previous questions and, possibly, answers to previous auxiliary questions, and (b) once auxiliary questions are resolved, the principal question is resolved as well.

This leads us to the notion of an *erotetic search scenario*. As the name suggests it is a scenario for solving a problem expressed in the form of a question. The pragmatic intuition behind the e-scenario is that it

> [...] provides information about possible ways of solving the problem expressed by its principal question: it shows what additional data should be collected if needed and when they should be collected. What is important, an e-scenario provides the appropriate instruction for every possible and just-sufficient, i.e., direct answer to a query: there are no "dead ends". [32, p. 110]

In this paper — following [33] — we will present the e-scenario as a family of interconnected sequences of the so-called erotetic derivations.[5]

[5] See also [30, 31] where the idea of e-scenarios has been presented for the first time. It is worth mentioning that e-scenarios can also be viewed as labelled trees (see [8]).

Erotetic derivation is defined as follows [33, pp. 110–111]:

DEFINITION 7 (Erotetic derivation). A finite sequence $\mathtt{s} = \mathtt{s}_1, \dots, \mathtt{s}_n$ of wffs is an erotetic derivation (e-derivation for short) of a direct answer $A$ to question $Q$ on the basis of a set of d-wffs $X$ iff $\mathtt{s}_1 = Q$, $\mathtt{s}_n = A$, and the following conditions hold:

(1) for each question $\mathtt{s}_k$ of $\mathtt{s}$ such that $k > 1$:
  (a) $\mathbf{d}\mathtt{s}_k \neq \mathbf{d}Q$,
  (b) $\mathtt{s}_k$ is implied by a certain question $\mathtt{s}_j$ which precedes $\mathtt{s}_k$ in $\mathtt{s}$ on the basis of the empty set, or on the basis of a non-empty set of d-wffs such that each element of this set precedes $\mathtt{s}_k$ in $\mathtt{s}$, and
  (c) $\mathtt{s}_{k+1}$ is either a direct answer to $\mathtt{s}_k$ or a question;
(2) for each d-wff $\mathtt{s}_i$ of $\mathtt{s}$:
  (a) $\mathtt{s}_i \in X$, or
  (b) $\mathtt{s}_i$ is a direct answer to $\mathtt{s}_{i-1}$, where $\mathtt{s}_{i-1} \neq Q$, or
  (c) $\mathtt{s}_i$ is entailed by a certain non-empty set of d-wffs such that each element of this set precedes $\mathtt{s}_i$ in $\mathtt{s}$;

An e-derivation is *goal-directed*: it leads from an initial question $Q$ to a direct answer to this question. Clause (1a) of the above definition requires that an auxiliary question (i.e., a question of an e-derivation different from $Q$) appearing in an e-derivation should have different direct answers than the initial question $Q$. Clause (1b) amounts to the requirement that each question of the e-derivation which is different from the initial question $Q$ must be e-implied by some earlier item(s) of the e-derivation. Clause (1c) requires that an immediate successor of an auxiliary question in the e-derivation must be a direct answer to that question or a further auxiliary question. Clause (2) enumerates reasons for which a d-wff may enter an e-derivation. Such a d-wff may be: (2a) an element of a set of d-wffs $X$; (2b) a direct answer to an auxiliary question; (2c) a consequence of earlier d-wffs.

DEFINITION 8 (Erotetic search scenario). A finite family $\Sigma$ of sequences of wffs is an erotetic search scenario (e-scenario for short) for a question $Q$ relative to a set of d-wffs $X$ iff each element of $\Sigma$ is an e-derivation of a direct answer to $Q$ on the basis of $X$ and the following conditions hold:

(1) $\mathbf{d}Q \cap X = \emptyset$;
(2) $\Sigma$ contains at least two elements;
(3) for each element $\mathtt{s} = \mathtt{s}_1, \dots, \mathtt{s}_n$ of $\Sigma$, for each index $k$, where $1 \leqslant k < n$:

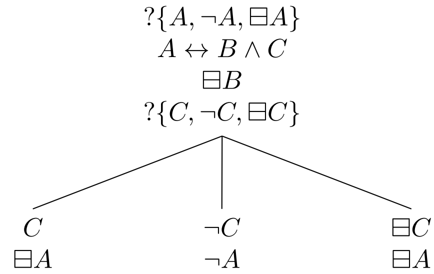


Figure 1. Schema of an e-scenario for the question $?\{A, \neg A, \boxminus A\}$ relative to the set of premises $A \leftrightarrow B \wedge C, \boxminus B$. Notice that the lack of knowledge about $B$ is expressed in the premises

(a) if $\mathtt{s}_k$ is a question and $\mathtt{s}_{k+1}$ is a direct answer to $\mathtt{s}_k$, then for each direct answer $B$ to $\mathtt{s}_k$: the family $\Sigma$ contains a certain e-derivation $\mathtt{s}^* = \mathtt{s}^*_1, \mathtt{s}^*_2, \ldots, \mathtt{s}^*_m$ such that $\mathtt{s}_j = \mathtt{s}^*_j$ for $j = 1, \ldots, k$, and $\mathtt{s}^*_{k+1} = B$;

(b) if $\mathtt{s}_k$ is a d-wff, or $\mathtt{s}_k$ is a question and $\mathtt{s}_{k+1}$ is not a direct answer to $\mathtt{s}_k$, then for each e-derivation $\mathtt{s}^* = \mathtt{s}^*_1, \mathtt{s}^*_2, \ldots, \mathtt{s}^*_m$ in $\Sigma$ such that $\mathtt{s}_j = \mathtt{s}^*_j$ for $j = 1, \ldots, k$ we have $\mathtt{s}_{k+1} = \mathtt{s}^*_{k+1}$.

The e-scenario has a tree-like structure with the main question as the root and direct answers to it as leaves. Other questions are auxiliary. An auxiliary question has another question as the immediate successor or it has all the direct answers to it as the immediate successors. In the latter case, the immediate successors represent the possible ways in which the relevant request for information can be satisfied, and the structure of the e-scenario shows what further information requests (if any) are to be satisfied in order to arrive at an answer to the main question. Exemplary e-scenarios of $\mathcal{L}^?_{\mathbf{K3}}$ are presented in figures 1–6. E-derivations being elements of an e-scenario will be called *paths* of this e-scenario. Examples of such paths are highlighted in figures 4 and 6. If an auxiliary question is a 'branching point' of an e-scenario, it is called a *query* of the e-scenario (see [33, pp. 112–113]). Among auxiliary questions, only queries are asked; the remaining auxiliary questions serve as erotetic premises only.

An introduction of ternary questions and e-scenarios for them allows us to express certain pragmatic features of the e-scenarios. Let us imagine that an agent $\mathtt{a}$ wants to establish whether $A$ is the case. The agent knows that: $A \leftrightarrow B \wedge C$, but knows nothing about $B$. We may now imagine that $\mathtt{a}$ solves his/her problem according to the e-scenario presented in Figure 1 (as can be observed, $\mathtt{a}$'s premise and the fact that $\boxminus B$ are incorporated in the initial premises of the e-scenario).

In this example $\boxminus B$ might be treated as an information gap. However, it can be observed that there is one possible course of events that will lead to the answer to the initial question despite a lack of knowledge about $B$ — namely the case, where the answer to the question $?\{C, \neg C, \boxminus C\}$ is negative (then the answer to the initial question is also negative). We may say that the proposed e-scenario offers three cognitive situations (from most to least preferable) — for more detailed discussion see [9]:

- A 'maximal' cognitive situation is represented by the path going through the answer $\neg C$, because it leads to $\neg A$, i.e., a definite answer to the initial question.
- A 'minimal' one is reflected by the path which goes through the answer $C$, as in this situation the questioning process ends up with some knowledge gains (despite the fact that we did not manage to solve the initial problem, we know $C$).
- A 'zero knowledge' situation is represented by the third path going through $\boxminus C$, because it finishes the questioning process without any knowledge gains.

## 2. Erotetic search scenarios and tutorial dialogues

An e-scenario may be viewed as providing a search plan for an answer to the initial question. This plan is relative to the premises a questioner has, and leads through auxiliary questions (and the answers to them) to the initial question's answer. The key feature of e-scenarios is that auxiliary questions appear in them on the condition that they are e-implied. Thus we may use e-scenarios to give some insights into questioning strategies used in dialogues. This approach is efficient for contexts where a questioner wants to obtain an answer to the initial question, which should not be asked directly (see [11, 24]). To obtain an answer to the initial question, the questioner usually asks a series of auxiliary questions in such situations. Answers to these questions, build up to an answer to the initial one. As it is presented and discussed in [9, 12] pragmatic interpretation of e-scenarios may be successfully used to model questions dependency in natural language dialogues. It is also possible to use e-scenarios for modelling broader parts of information seeking dialogues (including tutorial dialogues).

After [12, pp. 63–64] let us consider example from the BEE corpus and take a closer look on the way the dialogue is led by tutor.

*Example* 5. 1. TUTOR: Do you know where to attach them? Let's think about what it is that you are trying to accomplish by attaching them to the circuit. [*INITIAL PROBLEM*]

2. TUTOR: Do you know what it is that you are trying to accomplish? [*AUXILIARY QUESTION 1*]

   STUDENT: I think that I am trying to somehow measure current by setting up the circuit.

   TUTOR: That's right. [*ANSWER ACCEPTANCE*]

3. TUTOR: What needs to be the case in order for current to flow? [*AUXILIARY QUESTION 2*]

   STUDENT: am I to clip the red and black wires to wire 2?

   TUTOR: What do you believe would be accomplished by doing that?

   STUDENT: they would possibly complete the circuit.

   TUTOR: How would current flow in the circuit then? (what I mean is: where would it start? then where would it go? then where? etc.)

   STUDENT: maybe I should clip the red and black wires to area number 5 and 4?

   TUTOR: That is correct. [*ANSWER ACCEPTANCE*]

4. TUTOR: Which position would you attach the red clip to? [*AUXILIARY QUESTION 3*]

   STUDENT: position number 4

   TUTOR: Good. [*ANSWER ACCEPTANCE*]

5. TUTOR: OK, it seems you know how to hook the leads up... [*CONCLUSION*] [*BEE(F), stud47*]

In the presented dialogue T wants to check if S knows/understands how to attach clips to the circuit 1. To check this, T uses set of premises concerning this problem, and then asks three auxiliary questions (which express certain tasks for S: 2–4). After obtaining satisfactory answers to these questions T concludes that S really understands the initial problem, which is clearly expressed by the end of example 5.

It is possible to use e-scenario to represent a questioning agenda of T for Example 5. It should be stressed that I am not claiming here that tutor really uses e-scenario as his strategy for this tutorial dialogue. My point here is that e-scenario provides a convenient tool for modelling certain behaviours, we may describe them using e-scenario and justify certain questions asked by T.

T's beliefs and knowledge will be somehow reflected in the premises of the e-scenario. These beliefs and knowledge will concern the issues raised by tutorial dialogue context (namely understanding the problem under discussion). We may imagine two ways in which tutor will operationalise his way of checking whether student understands a given problem[6]. Let us start by the more restrictive approach, in which tutor formulates the condition of understanding as necessary conditions. T's premises would be formulated according to the following schema:

'If S understands the problem under discussion,
then S correctly solves task $X$.'

I will abbreviate this schema as $A \to C$, where $A$ stands for 'S understands the problem under discussion', and $C$ stands for 'S correctly solves task $X$'. The premises representing T's beliefs may be expressed with the following formulas: $A \to C_1, \ldots, A \to C_n$, $C_1 \wedge \ldots \wedge C_n \to A$, where $A$ is different from any of $C_i$ $(1 \leqslant i \leqslant n)$.

Schema of one of the possible e-scenarios which may be used as a strategy for T in this case is presented in Figure 2. In this case T's strategy is to check the previously formulated conditions one by one. If S fulfils every single one, then T becomes sure that S understands the problem under discussion. If S fails in at least one of the conditions, she is assumed not to have understood the given problem.

We may also imagine less restrictive strategy, in which T will reach the conclusion that S does not understand a given problem after she fails in answering all the auxiliary questions. In a case such as this T would formulate his/her premises according to the following scheme:

'If S correctly solves task $X$, then S understands
the problem under discussion'.

I will abbreviate this schema as $C \to A$ where $A$ stands for 'S understands the problem under discussion', and $C$ stands for 'S correctly solves task $X$'. The premises representing T's beliefs can be expressed by the following formulas: $C_1 \to A, \ldots, C_n \to A$, $\neg C_1 \wedge \ldots \wedge \neg C_n \to \neg A$.

[6] See also similar use of e-scenarios for the problem of the Turing test and modelling of hidden agendas presented in [10, 11, 24].

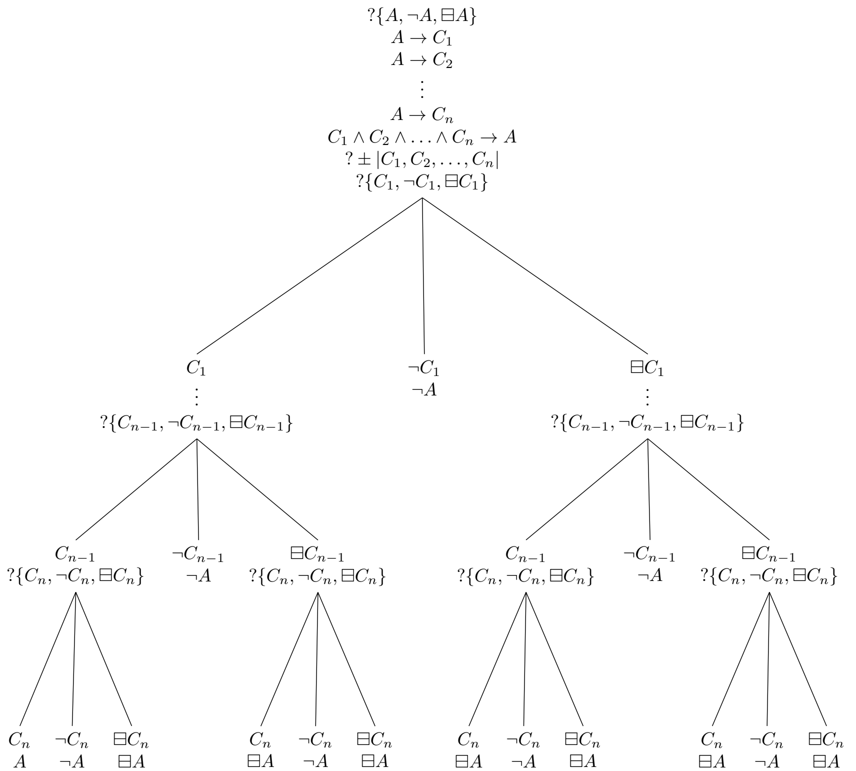


Figure 2. Schema for Tutor's questioning plan for the *necessary* conditions of understanding the problem under discussion

When we agree that T uses sufficient conditions of understanding the problem under discussion, then if S *fails* in all of them T becomes sure that S does not understand the problem — see Figure 3.

## 3. $\mathbf{DL(IEL)_T}$ — dialogue logic system for tutorial dialogues

In this section I provide a dialogue logic overlay for IEL background presented in previous section. For this purpose I will treat a tutorial dialogue as a form of questioning game between tutor and student. In the game tutor wants to solve a certain problem expressed by his initial question, i.e., a question whether student understands a problem under discussion. Tutor decomposes the initial question into series of auxiliary

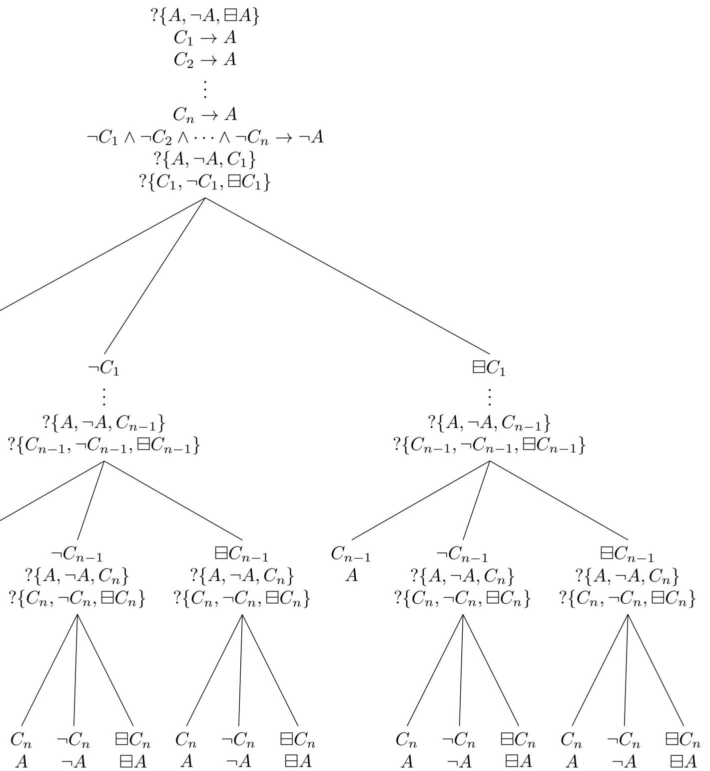


Figure 3. Schema for Tutor's questioning plan for the *sufficient* conditions of understanding the problem under discussion

questions (using e-scenario schemes presented in figures 2 and 3), that will be asked to a student. By obtaining answers to auxiliary questions tutor hopes to solve the initial problem. We assume that he will use an e-scenario as his questioning strategy. We also assume that student is providing information according to the best of her knowledge.

Intuitively we may describe the game as follows. Tutor asks questions and student provides answers. The game goes step-by-step. In one step tutor is allowed to:

- ask a question, or
- accept or reject an answer, or
- provide a justification for a question/solution, or
- end the game.

Student in one step can:

- provide an answer to a question;
- challenge the question ("Please, explain why you are asking this question");
- challenge the solution ("Please explain your assessment of my answers").

In a scenario where one of his questions is being attacked tutor is obliged to provide erotetic justification for the question (i.e., reveal a part of his questioning strategy).

I now propose a formal dialogue system $\mathrm{DL(IEL)_T}$ in order to precisely describe the rules of the game and the rules of executing tutors's questioning strategy. We will specify:

1. The taxonomy of locutions.
2. Commitment store rules.
3. Interaction rules.

A dialogue is a $k$-step finite game between tutor ($\mathsf{T}$) and student ($\mathsf{S}$). Each move consists of a locutionary event performed by one of the players (done one-by-one). The first move is always performed by $\mathsf{T}$, and it is a question.

Each step in a game will be presented as $\langle n, \phi, \psi, U\rangle$, where:
$n$ $(1 \leqslant n \leqslant k)$ is a number of the step of the dialogue,
$\phi$ is an agent producing the utterance,
$\psi$ is an addressee,
$U$ is the locution of the agent $\phi$.

For $\mathrm{DL(IEL)_T}$ I assume that $\mathsf{T}$ uses e-scenario based on a schemes presented in figures 2 or 3 as his questioning strategy for a game. E-scenario is a form of a dialogue game-board for $\mathsf{T}$ (see [2]). $\mathsf{T}$ performs his dialogical moves accordingly to a given e-scenario. As was mentioned before, an e-scenario represents a certain map of possible courses of events in a given questioning process. Each path of an e-scenario is one of the ways the process might go depending on the answers obtained to queries. One may imagine that executing such an e-scenario is simply eliminating these branches that are no longer possible after obtaining an answer to a given query. At the end of such an execution we will be left with only one path leading from the initial question through the auxiliary questions and answers to them to the solution to the initial question. Such a path will be called *the activated path of an e-scenario* (such a path is e-derivation, see Definition 7).

The intended reading of of $C$, $\neg C$ and $\boxminus C$ in e-scenario schemes for the presented system's context is the following. $C$ means that the tutor accepts the answer provided by a student (the answer is satisfactory/expected one). $\neg C$ means that the tutor does not accept the answer provided by a student (the answer is not satisfactory). As for $\boxminus C$ it covers the cases when the tutor is not able to decide whether the answer provided should be counted as satisfactory or unsatisfactory one — see discussion of Examples 3 and 4 in the introduction.

For the purposes of the interaction rules presented below let us also assume that for an e-scenario used by $\mathsf{T}$ as his questioning strategy the queries will be numbered as they appear in the scenario from top to bottom, from 1 to $k$ for the last query in a given scenario.

### 3.1. The taxonomy of locutions for DL(IEL)$_{\mathbf{T}}$

The following types of location are allowed in DL(IEL)$_{\mathrm{T}}$:

***Categorical statement.*** $A$, $\neg A$, $A \wedge B$, $A \rightarrow B$, $A \leftrightarrow B$, and $\boxminus A$. These are responses given by $\mathsf{S}$ or solutions declared by $\mathsf{T}$ at the end of the game.

***Question.*** Questions asked by $\mathsf{T}$.

***Logical statement.*** Justifications provided by $\mathsf{T}$: (i) stating that e-implication holds between a certain previous question (and possibly a set of declarative premises) and a question being challenged by $\mathsf{S}$; and (ii) justifications for a challenged solution (in a form of an e-derivation for this solution).

***Challenge.*** $\mathsf{S}$'s attack on a question asked by $\mathsf{T}$, or on a solution provided by $\mathsf{T}$ at the end of a game. $\mathsf{S}$'s challenge should be understood as a request for an explanation/reason behind asking an auxiliary question or $\mathsf{T}$'s assessment of her answers (i.e., solution).

### 3.2. Interaction rules for DL(IEL)$_{\mathbf{T}}$

Interaction rules allow us to specify the agent's behaviour in our game.

(In1) `Repstat`. No statement may occur if it is in the commitment store of both participants. This rule prevents pointless repetitions.

(In2) `Q-response`. When $\langle n, \mathsf{T}, \mathsf{S}, ?C_i \rangle$ (where $i \leqslant k$), then

1. $\langle n+1, \mathsf{S}, \mathsf{T}, C_i \rangle$; or
2. $\langle n+1, \mathsf{S}, \mathsf{T}, \neg C_i \rangle$; or

3. $\langle n+1, \mathsf{S}, \mathsf{T}, \boxminus C_i \rangle$; or
4. $\langle n+1, \mathsf{S}, \mathsf{T}, CH(?C_i) \rangle$.

The rule states that when Tutor asks an auxiliary question (one of the ones indicated by the e-scenario in use), Student may react by (1) providing an answer, which will be interpreted by Tutor as satisfactory/expected one; (2) providing an answer, which will be interpreted by Tutor as unsatisfactory; (3) providing an answer for which Tutor is not able to decide whether it is satisfactory or unsatisfactory one; (4) by challenging the question (i.e., asking for providing an explanation for the auxiliary question being asked by Tutor).

(In3A) `AccAnswReact`. When $\langle n-1, \mathsf{T}, \mathsf{S}, ?C_i \rangle$ and $\langle n, \mathsf{S}, \mathsf{T}, C_i \rangle$, then $\langle n+1, \mathsf{T}, \mathsf{S}, ACC(C_i) \rangle$ and check whether there is an auxiliary question $?C_j$ indicated by the e-scenario, where $j > i$:

1. if yes, then $\langle n+2, \mathsf{T}, \mathsf{S}, ?C_j \rangle$
2. if no, then $\langle n+2, \mathsf{T}, \mathsf{S}, SOL \rangle$

The intuition behind (In3A) is straightforward. For an answer, which is accepted, Tutor informs Student that it was acceptable, and then asks another auxiliary question indicated by the e-scenario (if there is one). In the case that all auxiliary questions indicated by the e-scenario were already used by Tutor, solution is announced.

(In3B) `NoAccAnswReact`. When $\langle n-1, \mathsf{T}, \mathsf{S}, ?C_i \rangle$ and $\langle n, \mathsf{S}, \mathsf{T}, \neg C_i \rangle$, then $\langle n+1, \mathsf{T}, \mathsf{S}, NACC(C_i) \rangle$ and check whether there is an auxiliary question $C_j$ indicated by the e-scenario, where $j > i$:

1. if yes, then $\langle n+2, \mathsf{T}, \mathsf{S}, ?C_j \rangle$
2. if no, then $\langle n+2, \mathsf{T}, \mathsf{S}, SOL \rangle$

In the case, where Student provides an answer, which is interpreted as an unacceptable, Tutor informs Student on this fact, afterwards $\mathsf{T}$'s actions are analogous to (In3A).

(In4) `IgnoranceResp`. When $\langle n-1, \mathsf{T}, \mathsf{S}, ?C_i \rangle$ and $\langle n, \mathsf{S}, \mathsf{T}, \boxminus C_i \rangle$, then

1. $\mathsf{T}$ checks his strategy whether there is a successful path of his e-scenario, if yes then $\langle n+1, \mathsf{T}, \mathsf{S}, ?C_j \rangle$ (where $j > i$);
2. if not, then $\langle n+1, \mathsf{T}, \mathsf{S}, \boxminus SOL = \boxminus A \rangle$ and the game ends.

The rule says what to do when Tutor cannot decide on the basis of the obtained answer whether Student understands a given issue. To take his move, Tutor first checks his e-scenario for the successful path (i.e., is there a path leading from the point where he is in the current state of the game, leading to a leaf of the e-scenario, which is not marked with $\boxminus$). If such a path exists (Tutor can reach the solution to the initial question despite the information gaps), then (1) Tutor asks the next auxiliary question from that path of his e-scenario. If not, (2) Tutor declares that he does not know the solution to the main problem and the instance of the game ends.

(In5) `Q-challenge`. When $\langle n, \mathsf{S}, \mathsf{T}, CH(?C_i)\rangle$ then $\langle n+1, \mathsf{T}, \mathsf{S}, LS(?C_i)\rangle$. The rule regulates Tutor's reaction to Student challenging the question asked. The challenge in this case means simply a Student's request to explain the reason why a given auxiliary question is being asked. Tutor provides a logical statement for that auxiliary question (in our case it should be a statement of the form: $\mathsf{Im}(?C_l, X, ?C_i)$, where $?C_i$ is the challenged question and $?C_l$ is a question appearing before $?C_i$ in the e-scenario). The intuition is that Tutor will state that the challenged question is e-implied by one of the previous questions (possibly on the basis of Tutor's declarative premises and answers already provided by Student).

(In6) `Q-challengeResp`. When $\langle n, \mathsf{T}, \mathsf{S}, LS(?C_i)\rangle$, then

1. $\langle n+1, \mathsf{S}, \mathsf{T}, C_i\rangle$; or
2. $\langle n+1, \mathsf{S}, \mathsf{T}, \neg C_i\rangle$; or
3. $\langle n+1, \mathsf{S}, \mathsf{T}, \boxminus C_i\rangle$.

After the logical statement for the challenged question is provided by Tutor, Student provides an answer according to his knowledge. Here, we assume that both tutor and student accept the normative yardstick for erotetic reasoning provided by e-implication. Because of this, we may say that Student provided with the logical statement for the challenged question of the form proposed in (In5) will accept the relevance of the justified question.

(In7) `SOLReaction`. When $\langle n, \mathsf{T}, \mathsf{S}, SOL\rangle$, then

1. $\langle n+1, \mathsf{S}, \mathsf{T}, ACC(SOL)\rangle$ and the game ends;
2. $\langle n+1, \mathsf{S}, \mathsf{T}, CH(SOL)\rangle$.

This is the regulation of Student's reaction to a solution being declared by Tutor. Student may (1) state that he/she agrees/accepts it — which will end the instance of the game; or (2) ask for a explanation concerning Tutor's assessment of her answers.

(In8) `SOLChallengeResp`. When $\langle n, \mathsf{S}, \mathsf{T}, CH(SOL)\rangle$, then $\langle n+1, \mathsf{T}, \mathsf{S}, LS(SOL)\rangle$ and the game ends.

`SOL-ChallengeResp` regulates justification of the solution move for Tutor. Analogically to `Q-ChallengeResp`, Tutor should provide a logical statement for the declared solution. In our case, such a logical statement is the activated path of an e-scenario used by Tutor for the game.

### 3.3. Commitment Store Rules for $\mathrm{DL(IEL)_T}$

Let us now have a look at the commitment store (ComSt) rules for $\mathrm{DL(IEL)_T}$. They state which locutions are added (+) or subtracted (−) from players' ComSt during the game.

| **Rule** | **Locution** | **T's ComSt** | **S's ComSt** |
|---|---|---|---|
| (CS1) | $?C_i$ | $+?C_i$ | $+?C_i$ |
| (CS2) | $C_i$ | $+C_i$ | $+C_i$ |
| (CS3) | $\neg C_i$ | $+\neg C_i$ | $+\neg C_i$ |
| (CS4) | $\boxminus C_i$ | $+\boxminus C_i$ | $+\boxminus C_i$ |
| (CS5) | $CH(?C_i)$ | $-?C_i$<br>$+CH(?C_i)$ | $-?C_i$<br>$+CH(?C_i)$ |
| (CS6) | $LS(?C_i)$ | $+?C_i$<br>$-CH(?C_i)$ | $+?C_i$<br>$+LS(?C_i)$ |
| (CS7) | $SOL$ | $+SOL$ | $+SOL$ |
| (CS8) | $CH(SOL)$ | $-SOL$<br>$+CH(SOL)$ | $-SOL$<br>$+CH(SOL)$ |
| (CS9) | $LS(SOL)$ | $+SOL$<br>$-CH(SOL)$ | $+SOL$<br>$+LS(SOL)$ |

The intuitions behind these rules are the following:

(CS1) When a question is asked by Tutor it goes into both players' ComSt.

(CS2)–(CS4) When an answer is provided by Student it goes into ComSt of both players.

(CS5) If the question asked by Tutor is challenged, it should be removed from both players' ComSt (this will allow us to ask it again in further moves). The information about the challenge is added.

(CS6) According to (In5), Tutor should react to a challenge to a question by providing a logical statement for this question. In terms of his ComSt the information about the challenge is removed ($-CH(?C_i)$). As for Student, she adds the logical statement for $?C_i$ and $?C_i$ itself to her ComSt. There is no need to add $LS(Q_i)$ to Tutor's ComSt, because this logical statement is generated on the basis of the activated part of an e-scenario used by Tutor. Notice that $CH(?C_i)$ is not removed from Student's ComSt (this prevents Student from challenging one question more than one time — see the `RepStat` interaction rule).

(CS8)–(CS9) These rules concerning solutions are analogous to (CS5) and (CS6).

### 3.4. $\mathrm{DL(IEL)_T}$ examples

Let us now consider examples of games expressed in $\mathrm{DL(IEL)_T}$. I will start from dialogue presented as Example 5 in Section 2. For this analysis I assume that $\mathsf{T}$ uses e-scenario based on the schema presented in Figure 2 and that he uses three sub-problems for his purposes here ($C_1$, $C_2$ and $C_3$). Such assumptions are necessary, because we are dealing only with a fragment of a whole tutorial dialogue. We may easily imagine that a tutor would change his strategies, e.g. from more restrictive ones to less restrictive ones during a long tutorial session (possibly depending on a student's performance).

| **Move** | **Turn** |
|---|---|
| $\langle 1, \mathsf{T}, \mathsf{S}, ?C_1 \rangle$ | *Do you know what it is that you are trying to accomplish?* |
| $\langle 2, \mathsf{S}, \mathsf{T}, C_1 \rangle$ | I think that I am trying to somehow measure current by setting up the circuit. |
| $\langle 3, \mathsf{T}, \mathsf{S}, ACC(C_1) \rangle$ | *That's right.* |
| $\langle 4, \mathsf{T}, \mathsf{S}, ?C_2 \rangle$ | *What needs to be the case in order for current to flow?* |
| $\langle 5, \mathsf{S}, \mathsf{T}, C_2 \rangle$ | maybe I should clip the red and black wires to area number 5 and 4? |
| $\langle 6, \mathsf{T}, \mathsf{S}, ACC(C_2) \rangle$ | *That is correct.* |
| $\langle 7, \mathsf{T}, \mathsf{S}, ?C_3 \rangle$ | *Which position would you attach the red clip to?* |
| $\langle 8, \mathsf{S}, \mathsf{T}, C_3 \rangle$ | position number 4 |
| $\langle 9, \mathsf{T}, \mathsf{S}, ACC(C_3) \rangle$ | *Good.* |
| $\langle 10, \mathsf{T}, \mathsf{S}, SOL = A \rangle$ | *OK, it seems you know how to hook the leads up...* |
| $\langle 11, \mathsf{S}, \mathsf{T}, ACC(SOL) \rangle$ | — |

In what follows I will use the following tabular form of reporting steps of a game.

| **Move** | **T's ComSt** | **S's ComSt** | **Int. rule** |
|---|---|---|---|
| $\langle n, \phi, \psi, U\rangle$ | $+/-U$ | $+/-U$ | In1–In8 (if any) |

Thus the analysis of Example 5 presented above may be expressed in the following manner.

**Game 1**

| **Move** | **T's ComSt** | **S's ComSt** | **Int. rule** |
|---|---|---|---|
| $\langle 1, \mathsf{T}, \mathsf{S}, ?C_1\rangle$ | $+?C_1$ | $+?C_1$ | — |
| $\langle 2, \mathsf{S}, \mathsf{T}, C_1\rangle$ | $+C_1$ | $+C_1$ | In2.2 |
| $\langle 3, \mathsf{T}, \mathsf{S}, ACC(C_1)\rangle$ | — | — | In3A |
| $\langle 4, \mathsf{T}, \mathsf{S}, ?C_2\rangle$ | $+?C_2$ | $+?C_2$ | In3A.1 |
| $\langle 5, \mathsf{S}, \mathsf{T}, C_2\rangle$ | $+C_2$ | $+C_2$ | In2.1 |
| $\langle 6, \mathsf{T}, \mathsf{S}, ACC(C_2)\rangle$ | — | — | In3A |
| $\langle 7, \mathsf{T}, \mathsf{S}, ?C_3\rangle$ | $+?C_3$ | $+?C_3$ | In3A.1 |
| $\langle 8, \mathsf{S}, \mathsf{T}, C_3\rangle$ | $+C_3$ | $+C_3$ | In2.1 |
| $\langle 9, \mathsf{T}, \mathsf{S}, ACC(C_3)\rangle$ | — | — | In3A |
| $\langle 10, \mathsf{T}, \mathsf{S}, SOL = A\rangle$ | $+A$ | $+A$ | In3A.2 |
| $\langle 11, \mathsf{S}, \mathsf{T}, ACC(SOL)\rangle$ | — | — | In7.1 |

The game starts by T's question. S provides answer accordingly to interaction rule (In2.2). At this point of the game both T and S have the auxiliary question and answer to it stored in their commitment stores. In the third step — following interaction rule (In3A) — T accepts the answer provided ("That's right."; this has no effect on commitment stores of players). In what follows T asks another auxiliary question indicated by the e-scenario in use with accordance to interaction rule (In3A.1). The rest of the game is played without any changes to this schema. T asks two more auxiliary questions (steps 4 and 7) and receives acceptable answers (steps 5 and 8). This leads to the conclusion that S understands a problem under discussion ("OK, it seems you know how

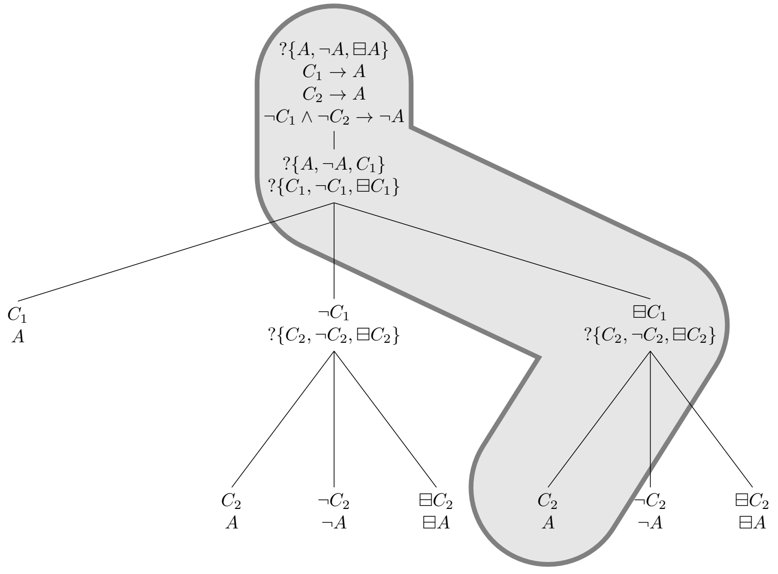


Figure 4. Schema of an e-scenario used by T in the Game 2A with the executed path highlighted

to hook the leads up...") in step 10. The game ends by S accepting the solution accordingly to interaction rule (In7.1).

Let us now consider a game motivated with the Example 3, i.e., a tutorial dialogue, where S will use 'I don't know answer' (see Figure 4). I will also use this game to demonstrate how the outcomes of a tutorial dialogue will differ depending on the strategy used by T. Let us start with the sufficient conditions of understanding adopted by T, i.e.. the less restrictive strategy — see figures 3 and 4. In both cases I assume that T uses two sub-problems for his purposes here ($C_1$, $C_2$) — see Figure 5.

The key point in this game is step 2, where S provides the $\boxminus C_1$ answer. At this point T plays accordingly to interaction rule `Ingorance-Resp`, i.e., T checks his strategy, whether there is successful path of his e-scenario. Let us remind, that T plays with sufficient conditions, thus he uses e-scenario in Figure 6. For this scenario a successful path (leading from $\boxminus C_1$ to a leaf of the e-scenario, which is not marked by $\boxminus$) exists, which allows T for asking another auxiliary question from the scenario (In4.1). For the sufficient conditions scenario it is enough for a student that, she will provide an acceptable answers to at least one of

**Game 2A**

| **Move** | **T's ComSt** | **S's ComSt** | **Int. rule** |
|---|---|---|---|
| $\langle 1, \mathsf{T}, \mathsf{S}, ?C_1 \rangle$ | $+?C_1$ | $+?C_1$ | — |
| $\langle 2, \mathsf{S}, \mathsf{T}, \boxminus C_1 \rangle$ | $+\boxminus C_1$ | $+\boxminus C_1$ | In2.3 |
| $\langle 3, \mathsf{T}, \mathsf{S}, ?C_2 \rangle$ | $+?C_2$ | $+?C_2$ | In4.1 |
| $\langle 4, \mathsf{S}, \mathsf{T}, C_2 \rangle$ | $+C_2$ | $+C_2$ | In2.1 |
| $\langle 5, \mathsf{T}, \mathsf{S}, ACC(C_2) \rangle$ | — | — | In3A |
| $\langle 6, \mathsf{T}, \mathsf{S}, SOL = A \rangle$ | $+A$ | $+A$ | In3A.2 |
| $\langle 7, \mathsf{S}, \mathsf{T}, ACC(SOL) \rangle$ | — | — | In7.1 |

Figure 5.

the auxiliary questions asked by $\mathsf{T}$. It is the case in step 4 of the game. This situation will change when $\mathsf{T}$ will change his strategy.

Now, the game will be played with necessary conditions used (see figures 2 and 6 for e-scenario used). In this case the conclusion reached by is different for the same $\mathsf{S}$ performance.

**Game 2B**

| **Move** | **T's ComSt** | **S's ComSt** | **Int. rule** |
|---|---|---|---|
| $\langle 1, \mathsf{T}, \mathsf{S}, ?C_1 \rangle$ | $+?C_1$ | $+?C_1$ | — |
| $\langle 2, \mathsf{S}, \mathsf{T}, \boxminus C_1 \rangle$ | $+\boxminus C_1$ | $+\boxminus C_1$ | In2.3 |
| $\langle 3, \mathsf{T}, \mathsf{S}, ?C_2 \rangle$ | $+?C_2$ | $+?C_2$ | In4.1 |
| $\langle 4, \mathsf{S}, \mathsf{T}, C_2 \rangle$ | $+C_2$ | $+C_2$ | In2.1 |
| $\langle 5, \mathsf{T}, \mathsf{S}, ACC(C_2) \rangle$ | — | — | In3A |
| $\langle 6, \mathsf{T}, \mathsf{S}, SOL = \boxminus A \rangle$ | $+\boxminus A$ | $+\boxminus A$ | In3A.2 |
| $\langle 7, \mathsf{S}, \mathsf{T}, CH(\boxminus A) \rangle$ | $-\boxminus A$<br>$+ CH(\boxminus A)$ | $-\boxminus A$<br>$+ CH(\boxminus A)$ | In7.2 |
| $\langle 8, \mathsf{T}, \mathsf{S}, LS(\boxminus A) \rangle$ | $+\boxminus A$<br>$-CH(\boxminus A)$ | $+\boxminus A$<br>$+LS(\boxminus A)$ | In8 |

Where $LS(\boxminus A)$ announced in the the eight step of the game is the following e-derivation:

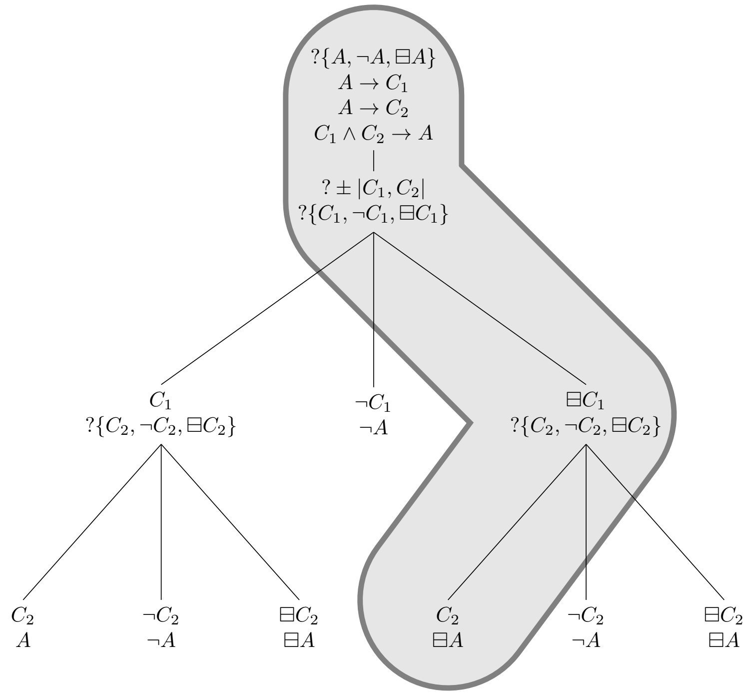


Figure 6. Schema of an e-scenario used by T in the Game 2B with the executed path highlighted

$LS(\boxminus A) = ?\{A, \neg A, \boxminus A\}; A \to C_1; A \to C_2; C_1 \wedge C_2 \to A; ? \pm |C_1, C_2|;$ $?\{C_1, \neg C_1, \boxminus C_1\}; \boxminus C_1; ?\{C_2, \neg C_2, \boxminus C_2\}; C_2; \boxminus A.$

Steps from 1 to 5 are the same for games 2A and 2B. The solution is different, because two different strategies were used by T in these two games. In the third step of 2B, when T checks his strategy for a successful path, it is a different path than in the case of the 2A game. Here the only conclusive solution which may be reached by T is $\neg A$ in the case, when S will provide an unacceptable answer to the second auxiliary question — see Figure 6.

In Game 2B I have added additional S's behaviour in step 7 related to the solution of this game. S asks for an explanation for the solution by challenging it accordingly to interaction rule (In7.2). The last step od the game is a logical statement provided by T, which serves as an explanation for the reached solution of 2B. At this step T introduces the executed path of the e-scenario in use. This path is highlighted in Figure 6.

Now we will consider game motivated with Example 2. In this game $\mathsf{S}$ provides an answer to an auxiliary question, which is not accepted by $\mathsf{T}$. I assume that $\mathsf{T}$ uses two sub-problems for his purposes here ($C_1$, $C_2$) and that he plays accordingly to necessary conditions.

**Game 3**

| **Move** | **T's ComSt** | **S's ComSt** | **Int. rule** |
|---|---|---|---|
| $\langle 1, \mathsf{T}, \mathsf{S}, ?C_1 \rangle$ | $+?C_1$ | $+?C_1$ | — |
| $\langle 2, \mathsf{S}, \mathsf{T}, C_1 \rangle$ | $+C_1$ | $+C_1$ | In2.2 |
| $\langle 3, \mathsf{T}, \mathsf{S}, ACC(C_1) \rangle$ | — | — | In3A |
| $\langle 4, \mathsf{T}, \mathsf{S}, ?C_2 \rangle$ | $+?C_2$ | $+?C_2$ | In3A.1 |
| $\langle 5, \mathsf{S}, \mathsf{T}, \neg C_2 \rangle$ | $+\neg C_2$ | $+\neg C_2$ | In2.1 |
| $\langle 6, \mathsf{T}, \mathsf{S}, NACC(C_2) \rangle$ | — | — | In3B |
| $\langle 7, \mathsf{T}, \mathsf{S}, SOL = \neg A \rangle$ | $+\neg A$ | $+\neg A$ | In3B.2 |
| $\langle 11, \mathsf{S}, \mathsf{T}, CH(\neg A) \rangle$ | $-\neg A$<br>$+CH(\neg A)$ | $-\neg A$<br>$+CH(\neg A)$ | In7.2 |
| $\langle 12, \mathsf{T}, \mathsf{S}, LS(\neg A) \rangle$ | $-CH(\neg A)$<br>$+\neg A$ | $+LS(\neg A)$<br>$+\neg A$ | In8 |

Where the logical statement for the solution provided in the twelfth step of this game is the following: $LS(\neg A) =?\{A, \neg A, \boxminus A\}; A \rightarrow C_1; A \rightarrow C_2; C_1 \wedge C_2 \rightarrow A;$
$? \pm |C_1, C_2|; ?\{C_1, \neg C_1, \boxminus C_1\}; C_1; ?\{C_2, \neg C_2, \boxminus C_2\}; \neg C_2; \neg A$

In the sixth step of the game the answer provided by $\mathsf{S}$ is interpreted as unsatisfactory by $\mathsf{T}$, and $\mathsf{T}$'s actions in steps 6 and 7 are done accordingly to interaction rule (In3B). $\mathsf{T}$ plays the game (3) with necessary conditions, thus in the step 7 he will not find any other additional auxiliary questions predicted by the e-scenario in use (middle path of e-scenario is realised). Similarly to game (2B) $\mathsf{S}$ asks for explanation concerning the assessment of her answers (steps 11 and 12).

As the last example, I present a game, where $\mathsf{S}$ will challenge an auxiliary question asked by $\mathsf{T}$. For this case I assume that $\mathsf{T}$ uses two sub-problems for his purposes here ($C_1$, $C_2$) and that he plays accordingly to sufficient conditions.

**Game 4**

| **Move** | **T's ComSt** | **S's ComSt** | **Int. rule** |
|---|---|---|---|
| $\langle 1, \mathsf{T}, \mathsf{S}, ?C_1\rangle$ | $+?C_1$ | $+?C_1$ | — |
| $\langle 2, \mathsf{S}, \mathsf{T}, CH(?C_1)\rangle$ | $-?C_1$ <br> $+CH(?C_1)$ | $-?C_1$ <br> $+CH(?C_1)$ | In2.4 |
| $\langle 3, \mathsf{T}, \mathsf{S}, LS(?C_1)\rangle$ | $+?C_1$ <br> $-CH(?C_1)$ | $+?C_1$ <br> $+LS(?C_1)$ | In3A |
| $\langle 4, \mathsf{S}, \mathsf{T}, \boxminus C_1\rangle$ | $+\boxminus C_1$ | $+\boxminus C_1$ | In2.3 |
| $\langle 5, \mathsf{T}, \mathsf{S}, ?C_2\rangle$ | $+?C_2$ | $+?C_2$ | In4.1 |
| $\langle 6, \mathsf{S}, \mathsf{T}, C_2\rangle$ | $+C_2$ | $+C_2$ | In2.1 |
| $\langle 6, \mathsf{T}, \mathsf{S}, ACC(C_2)\rangle$ | — | — | In3A |
| $\langle 7, \mathsf{T}, \mathsf{S}, SOL = A\rangle$ | $+A$ | $+A$ | In3A.2 |
| $\langle 11, \mathsf{T}, \mathsf{S}, ACC(SOL)\rangle$ | — | — | In7.1 |

Where the logical statement for an auxiliary question $?C_1$, provided in the third step of this game, is the following: $LS(?C_1) = \mathsf{Im}(?\{A, \neg A, \boxminus A\}, \{C_1 \to A, C_2 \to A, \neg C_1 \wedge \neg C_2 \to \neg A\}, ?\{A, \neg A, C_1\})$ and $\mathsf{Im}(?\{A, \neg A, C_1\}, \emptyset, ?\{C_1, \neg C_1, \boxminus C_1\})$.

In the step 2 of game (4) S plays with interaction rule (In 2.4) and instead of simply providing an answer to the auxiliary question, she challenges it. The intuition behind such a challenge is the following: "Please, explain me why you ask me this question.". As his step, T is obliged (see (In3A)) to provide a logical statement for the auxiliary question $?C_1$. In the presented approach such a logical statement shows how the auxiliary question under discussion is reached by using e-implication.

## Summary

In this paper I propose a formal dialogue system inspired by works [1, 7], where logic is used as an underpinning of a formal dialogue system in order to check the correctness of certain dialogue moves. The system proposed here implements the same idea to the domain of tutorial dialogues and questioning agendas. Thus the choice of IEL as a background logic for $\mathrm{DL(IEL)_T}$. The system relies on the normative concepts of e-implication and e-scenario developed within IEL. As I presented adding dialogue logic overly to IEL concepts allows for modelling and generating behaviours observed in tutorial dialogues. For this purpose I have used natural language examples retrieved from BEE.

$\mathrm{DL(IEL)_T}$ allows for intuitive and precise description of questioning related behaviours in the context of tutorial dialogues. As discussed in [12] such an approach may serve as an integrative framework for applying IEL concepts for grasping natural language dynamics and information exchange. The advantage of the proposed approach is that it is fairly universal and modular. It can be modified on the level of rules used to describe the dynamics of questioning process. E.g. we may add new locution types, or modify interaction rules to obtain the desired behaviours of our agents. What is more, we can also adapt IEL tools used here in order to tailor them better to our needs (one can e.g. use the e-scenario based on the notion of weak e-implication [25], falsificationist e-implication [5] or epistemic e-implication [16, 17, 22]).

It should be pointed however, that $\mathrm{DL(IEL)_T}$ requires certain restrictions and idealisations as discussed in the paper. The most obvious idealisation is related to the strategies considered (i.e., the necessary and sufficient one) for conditions of understanding. Such a simplification allows for modelling only smaller parts of dialogues retrieved from BEE. For the whole transcripts it would be necessary to introduce a mechanism of changing $\mathsf{T}$'s strategies and also new (mixed or even probabilistic) strategies.

One of other potential developments of $\mathrm{DL(IEL)_T}$ may be enriching student's repertoire of locutions with questions. Natural candidates will be here clarification requests and questions considering the way of answering the initial question — see the corpus study of question responses in [13]. Such an extension of the proposed system would require more extensive corpus studies (of tutorial dialogues) and considering discussions related to the role of students' questions in teaching contexts as presented in [4].

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