CO-OPERATIVE LEARNING STRATEGIES FOR INTELLIGENT TUTORING SYSTEMS

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Abstract

Intelligent Tutoring Systems (ITS) are evolving towards a more co-operative relationship between the system and the student. More and more, learning is considered as a constructive process rather than a simple transfer of knowledge. This trend has brought to light new co-operative tutoring strategies. One of these tutoring strategies, the learning companion, is designed to overcome some of the limitations of the classical tutoring model; it involves a student and two simulated participants, a tutor and another student. More recently we proposed the learning by disturbing strategy, in which the simulated student is a troublemaker with the role to deliberately disturb the human student.

In this article, we describe the learning by disturbing strategy and compare it with that of the learning companion. In addition, we draw links to the psychology of learning and in particular to the cognitive dissonance theory. We develop an indicator that measures discord between the ideas, helping us to pinpoint the concepts that learners most likely misunderstand. This allows us to plan more efficiently the interventions of the troublemaker.
Introduction

The goal of an intelligent tutoring system (ITS) is to reproduce the behaviour of an intelligent (competent) human tutor who can adapt his teaching to the specific needs of the learner. Initially, the control of training was assumed by the tutor (prescriptive approach), and not by the learner. More recent ITS developments consider a co-operative approach between the learner and the system, which can simulate various partners, such as a co-learner, a learning companion, and a troublemaker; we called these partners pedagogical actors (Frasson and al, 1996). This evolution progressively highlighted two fundamental characteristics: (1) learning in ITS is a constructive process (Frasson, Mengelle & Aïmeur, 1997) involving several pedagogical actors and (2) to improve it, various co-operative learning strategies can be used, such as one-on-one tutoring, learning with a co-learner, learning by teaching or learning by disturbing.

To make these strategies effective we have to measure the weaknesses of the learner and more specifically the discord between the learner's ideas (cognitive dissonance (Festinger, 1989)). This is to gain better understanding about which strategy is best suited, when to use it and which concepts need to be emphasized.

Being able to detect cognitive dissonance enables the system to emphasize the concepts that the student has not mastered, and this will improve learning. This dissonance can be detected in all learning strategies but is most evident in the learning by disturbing strategy since it is deliberately triggered.

In this article we show that we can detect and measure internal conflicts of a learner. To accomplish this we deliberately provoke a debate between the troublemaker and the learner in order to test the learner's confidence in his knowledge and to make him aware of possible internal conflicts. The debate consists of a difference in opinion between the learner and the troublemaker (specialised tutor), and this difference is introduced to reach an important pedagogical goal: making the learner evaluate his own opinion and cognitive schemata and correcting his internal conflicts, if necessary (Aïmeur & Frasson, 1996; Aïmeur, Dufort, Leibu & Frasson, 1997; Aïmeur, Dufort & Frasson, 1997).
To be successful, we must identify those knowledge units in the curriculum (material to be taught) (Nkambou, Lefebvre & Gauthier, 1996) which are likely to be misunderstood and carefully plan the interventions of the troublemaker.

Three networks of knowledge (network of objectives, network of capabilities and network of resources) form the curriculum model we use. Some concepts are critical for the understanding of the course and a higher importance is assigned to them. In order to detect these important concepts, we use the theory of cognitive dissonance. In particular, we try to induce a dissonance in the learner with regards to the critical concepts and we observe the attitude he adopts to reduce this dissonance. Faced with dissonant information from the troublemaker, the learner will have to evaluate his own beliefs. Depending on his self-confidence, he will be more or less influenced by the troublemaker and will have to defend his point of view.

This article explores two avenues: in the second section we discuss teaching strategies and more specifically the learning by disturbing strategy; in the third section we deal with the cognitive dissonance theory. This allows us to clarify the principles that we use to measure the dissonance, given the three factors identified by Festinger. Finally we show how the formulas we developed can be used in a real intelligent tutoring system.

**Learning strategies in ITS**

**Co-operative strategies**

The principle of co-operative tutoring systems (also called social learning systems) is based on the use of the computer [as a way to exchange, control and build knowledge], and not as a directive training tool but instead. Several experiences have shown that two persons working together could learn more than in individual training. Constructivist approaches assess that the learner builds his or her own knowledge using his/her experience and interaction with the real working environment. Learning in context states that knowledge construction results from a
common interaction with the real world (including not only specific aspects of the domain but also social, cultural and historical aspects) using the context (Clancey, 1992).

Several models have been developed which are generally called social learning systems, co-operative systems, or collaborative systems. If both co-operative and collaborative systems can be considered as social learning systems, there is a difference between co-operation and collaboration. Collaboration requires a joint action of the participants and a mutual understanding of the task to execute, each participant having his or her own objectives. Co-operation requires to share the responsibilities between the participants for executing a task and the knowledge of mutual objectives (Baker, 1993). In both cases social agents can be computer simulated or real humans sharing a single computer or distributed on a network of computers. Also, the role of the learner and the teacher can be interchanged and this aspect provides a variety of learning strategies that we review in the following section.

**Peer learning**

Co-operative learning systems adopt a constructive approach using the computer more as a partner than as a tutor. Multiple agents that are either computer simulated or real human beings can work on the same computer or share a computer network. Chan and Baskin proposed a three-agent learning situation (Chan & Baskin, 1990), which consists in a co-operation between a human learner and a simulated learning companion. They learn together under the guidance of the tutor. The companion and the learner perform the same task and exchange ideas on the problem. The learner and the co-learner (the companion) work together and ask the tutor for help only if they cannot find a solution.

The learning by disturbing strategy (Aïmeur & Frasson, 1996; Aïmeur, Dufort, Leibu & Frasson, 1997) suggests that the computer can simulate two agents: a tutor and a troublemaker. The level of competence of the troublemaker is superior than that of the learner, in order to provide reasonable competition. In addition, it has some pedagogical knowledge which can help it to plan its interactions efficiently.
For the strategy to be pedagogically sound, the troublemaker proposes erroneous suggestions to the student emphasizing some of the finer points of the exercise at hand.

The learning by disturbing strategy

In this section we describe the learning by disturbing strategy by describing the participants and their roles and by comparing the strategy with that of the peer who learns with a learning companion.

Description:
The learning by disturbing strategy implicates three participants:

- The tutor presents to the team of students both the lessons and the exercises to be solved. It is the tutor who controls both the content and the length of the session. At any time, the tutor may intervene to help one of the students in their task, and, eventually, he evaluates the performance of the learner.

- The learner is the human student who is using the ITS. The learner interacts with the other participants via either pseudo-natural language or symbolic dialogue. The system maintains at all times a model of the learner which describes the state of the student’s knowledge relative to the system’s objectives and the student’s emotional state. The later is particularly relevant to the troublemaker strategy since it is important to gage the student’s confidence levels to plan the troublemaker’s actions.

- The troublemaker appears to be a simulation of a student working with the learner. In fact the troublemaker possesses both pedagogical expertise and a level of knowledge of the domain comparable to that of the tutor. The troublemaker uses this pedagogical expertise to maximise the impact of its interventions. The role of the troublemaker is to unsettle the student by proposing solutions which are sometimes truthful but other times erroneous. This tests the student’s self-confidence and obliges him to defend his point of view. We believe
that, in certain condition, this argumentation increases the student’s motivation and increases learning.

The reader may ask why the tutor does not ensure both the teaching and the trouble-making functions. The answer is clear. In the framework of intelligent tutoring systems, one can not afford to have the student lose confidence in the tutor. In fact the troublemaker by making suggestions which are sometimes correct but also sometimes erroneous will inevitably lose credibility in the eyes of the student. We present the troublemaker as a student who works with the learner without revealing its true intentions. The learner will never know that the troublemaker is in fact a tutor with a specialised role, that of testing and provoking the student.

**Comparison between the learning companion strategy and learning by disturbing**

The learning by disturbing strategy is relatively new and is still under development. Those who are accustomed to the learning companion strategy may well ask themselves: why do we need the learning by disturbing strategy? The justification given in (Aïmeur & Frasson, 1996) is that there is a need to test the self-confidence of the learner, to introduce a new form of motivation, to increase the degree of stimulation, and to reinforce the knowledge of the learner.

However, each method presents benefits and weaknesses. To appreciate more precisely their differences we will consider some criteria in which innovative work has been done and that can improve the efficiency of an ITS. They concern the self-confidence of the learner, his motivation in learning and the pedagogical knowledge implied. In the following we briefly review of these criteria in the two strategies: the companion and learning by disturbing.

- **Learner's self-confidence**

  With the learning companion, the learner needs to be self-confident in order to interact with him. Learning by disturbing forces the learners to be even more self-confident in their actions or conclusions and to distinguish between wrong and correct solutions. In addition, it strengthens the knowledge acquisition process. The learner confronts the troublemaker, facing its
position and needing to prove that he has learned correctly. Ultimately, he could feel a certain pleasure at giving proof of his capacity in front of the troublemaker.

- **Motivation in learning**

  With the companion, although an evaluation has to be done by the tutor, the motivation is based on a feeling of emulation. As we mentioned earlier, we need to know the self-confidence of the learner, to introduce a new form of motivation, to increase the degree of stimulation, and to anchor the knowledge in the learner. We can also make a link between the learning by disturbing strategy and the argument teaching method (Schank & Jona, 1991). In both methods, the presence of controversy and the discussions that follow (between co-learners) have a positive effect on learning. The idea that the discussions in a group learning situation increase motivation is not new. Roschelle (Roschelle, 1992) noted that "Piaget and his followers tended to see collaboration as producing productive individual cognitive conflict – disequilibrium drives conceptual change."

- **Pedagogical knowledge**

  Unlike the learning companion, the troublemaker possesses pedagogical knowledge. Despite the fact that it appears to be a student, in this respect it is acting as a tutor. Two points are to be noted:

  - Both the troublemaker and the tutor have complete knowledge of the domain. This is not necessarily the case for the learning companion.
  - In addition, the troublemaker possesses specific pedagogical knowledge, which the tutor does not have: When to disturb? How far to argue a erroneous point?

  We will use the cognitive dissonance theory to show how the troublemaker strategy can be effectively used. Before this we will introduce the different types of conflict that can occur in an ITS.
Cognitive dissonance

Each of us memorises at a given moment a certain number of facts, either truthful or false, concerning one self or our environment. Social psychologists of the 50s called these facts cognitions, which refer to conscious representations of fact in our mind. They can be concepts, ideas, knowledge, opinions, or beliefs, etc. They can refer to one self ("I am interested in computer science"), to one's behaviour ("I am waiting for Suzanne"), to one's social environment ("My neighbours are fighting again") or to one's environment ("The sky is blue"). Most of the cognitions that constitute our cognitive environment are not independent from each other. On the contrary they are related in ways that can be perfectly harmonious but can also be quite uncomfortable.

Cognitive dissonance is a theory originally developed by Festinger, which had a great impact on the social psychology community. According to this approach, a cognition represents an element of knowledge. The cognitions can be in either a relevant or a not relevant relation with respect to each other. When they are in a relevant relation they can interact, imply each other, contradict each other, or contribute to each other. The theory is only interested in cognitions which are in a relevant relation with each other and these can either be consonant (consistent) or dissonant (inconsistent). More formally, if x and y are cognitions then they are in a consonant state if x implies y or if x contributes to y. They are in a dissonant state if x contradicts y. Like motivational states of hunger or thirst, the state of dissonance is unpleasant and prompts the individual to attempt to reduce that dissonance.

Example:
Consider someone who buys an expensive car but discovers that it is not comfortable on long drives. Dissonance exists between his beliefs that he has bought a good car and that a good car should be comfortable. Dissonance could be eliminated by deciding that it does not matter since the car is mainly used for short trips (reducing the importance of the dissonant belief) or focusing on the cars strengths such as safety, appearance, handling (thereby adding more consonant beliefs). The dissonance could also be eliminated by getting rid of the car, but this behavior is a lot harder to achieve than changing beliefs.
Definition

Festinger's definition of cognitive dissonance is the perception, by a subject, of a difference, of variable intensity, between what has been previously perceived and learned and new information. This process is illustrated by figure 1.

![Figure 1. Steps in the cognitive dissonance process (Dufort, Aïmeur & Frasson, 1997).](image)

Festinger adds that, essentially, inertia makes us accept what we believe to be true. Nevertheless, there exist situations when we are exposed by force to contradictory information. A feeling of cognitive dissonance so triggered will start the process illustrated in figure 1.

Festinger links strongly cognitive dissonance and internal motivation: "The existence of dissonance, being psychologically uncomfortable, will motivate the person to try to reduce the dissonance and achieve consonance. (...) In short, I am proposing that dissonance, that is the existence of non-fitting relations among cognitions, is a motivating factor in its own right." (Festinger, 1957).

A key feature of Festinger's theory is the expectations of the subject. In fact, the subject seeks to corroborate his conception of the environment by what they perceive. "New information may become known to a person, creating at least a momentary dissonance with existing
knowledge, opinion or cognition concerning behaviour. Since a person does not have complete and perfect control over the information that reaches him and over events that can happen in his environment, such dissonance may easily arise." (Festinger, 1989).

An individual experiencing cognitive dissonance may lead to negative consequences:

- the individual may incorporate inconsistent and contradictory knowledge into his cognitive schema and then use them in a dysfunctional manner. This is exemplified when a student, who believes from childhood that two objects of unequal mass will fall at different velocities, is taught the contrary. It is possible that this student will maintain both beliefs, being able to state the law of physics correctly but answering incorrectly an exercise on an exam. (It is important to note that a single piece of information can be represented in different manners and then stored as different cognitive schema. This poor assimilation of information is precisely the type of error that an ITS can detect and correct; see step 2 of figure 1.)
- the individual may try to avoid the situation that has caused the dissonance, even if this means committing an error. This reflex is instinctive, unconscious, and depends on the personality of the subject and his perception of the resources available to him. For example, a student who does not understand a subject may decide to no longer study it unless forced to. Another student in the same circumstances may simply refuse to ask questions in class from fear of being mocked.
- the individual may become suspicious of new information and, therefore, his confidence when interacting with others may diminish.

Festinger adds that, essentially, inertia makes us accept what we believe to be true. Additionally, any information which does not seem relevant to the subject does not motivate. Nevertheless, there exist situations when we are exposed by force to contradictory information. A feeling of cognitive dissonance so triggered will start the process illustrated in figure 1.

Therefore, all individuals will experience cognitive dissonance while interacting with their environment. A very common source is the interaction individuals have with other people:
"When a person is confronted with an opinion contrary to its own which is held by people like himself, he experiences dissonance" (Festinger, 1989).

The intensity of such dissonance depends on two factors:
- the perceived competence of the person or group expressing the contradictory opinion (in our case this is the perceived competence of the troublemaker), and
- the emotional relationship to the person or group expressing the contradictory opinion (in our case this is related to the emotional relationship with the troublemaker).

The individual experiencing cognitive dissonance triggered by another person can react in four ways:
1. Dismissing the subject of dispute as being unimportant
2. Dismissing the other person as being unimportant
3. Attempting to eliminate the dissonance by changing his own opinion (by letting himselfs be convinced) or by attempting to change the opinion of the other person (in particular by initiating a debate with that person).
4. Seeking new information in his environment which would support his opinion. For example in a community (such as a system with several participants) the individual could seek social support.

**Learning by disturbing as a way to trigger cognitive dissonance**

The following points describe the learning by disturbing strategy in the context of cognitive dissonance theory:

(1) A cognitive dissonance is triggered by the troublemaker's interventions;
(2) At that time, the troublemaker is the only available source of information;
(3) In order to reduce the dissonance the learner is motivated to search for new information in his environment;

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1 However, one can imagine a strategy in which the tutor is accessible during the debate between the student and the troublemaker.
(4) The mechanisms used are dialogue and debate with the troublemaker and this process has two outcomes the student can let himself be convinced, or the student can change his environment by convincing the troublemaker.

Finally, two factors influence the outcome of this debate:

- the confidence that the student has in his cognitive schema, and;
- the ability the troublemaker has to express its ideas in a convincing manner.

It is interesting to ask what impact each intervention of the troublemaker should have. It is clear that cognitive dissonance should not be the result each and every time, so when is it important to disturb the student? A few important points to keep in mind are:

- If the student's confidence seems to be dropping even though he is correct, it is important to have the troublemaker agreeing with him, to reinforce the student's beliefs.
- In some cases the troublemaker can make such a big error that there is no doubt that the student can correct it. This will increase the student's confidence and gives him a feeling of competence.
- When the student begins to develop self-confidence, the troublemaker's suggestions should become more aggressive in order to disturb the student. It is at these moments that the tutor can intervene to demand consensus so that the student does not dismiss the troublemaker out of hand.

A note on measuring cognitive dissonance

First we need to specify clearly what we mean by “measuring cognitive dissonance”. In addition, to the fact that this is a difficult thing: "Localizing a gap in someone's knowledge is difficult." (VanLehn, Jon & Chi, 1992), it is necessary to clearly express what it is that we are calculating.
Joule (Vallerand & Thill, 1993) showed that the behaviour of an individual has a specific role in the interpretation of Festinger’s theory. It is this behaviour that is the origin of dissonance and that guides each stage of cognitive dissonance. A number of specific observable behaviours are associated to any given stage whose key is cognitive dissonance. For example an individual feeling guilty when smoking may light a cigarette but put it out after a few puffs. An active means of observing the individual is to ask him questions. “Do you believe that smoking is bad for your health?” and “Do you want to stop smoking?”. If the individual answers respectively yes and no then we can affirm that we have detected cognitive dissonance.

**Proposition 1**: The steps of the method an individual uses to solve a problem, or the answers to a test constitute behaviours from which we can detect cognitive dissonance.

In order to accept this proposition we have to privilege laxist interpretation of Festinger’s theory which states that a subject is in a state of cognitive dissonance whenever two of his cognitions are in a dissonant state. This allows us to consider the set of cognitions of an individual as potentially dissonant. The other interpretation of the theory, the radical one, proposes a more restrictive approach, which draws a link between cognitive dissonance and a state of tension; the distinction is between cognitive dissonance (existence of tension) and incoherence (state of ideas).

**Proposition 2**: Any related cognitions that are in a state of incoherence are considered dissonant, independently of the state of tension present in the individual.

Of course it is not possible to detect all of the cognitive dissonances present in an individual or even to confirm with great certainty that what was detected is in fact cognitive dissonance. As we will see later we can only detect part of existing dissonance with tests; this part varies based on the brut score obtained on the test. Even so, we believe that the result can in most cases guide interventions of the pedagogue or the tutoring system.
Finally, it is important to note that when Heider and his successors (see Heider, 1958; Morissette, 1958) allow themselves to quantify the total rate of disequilibrium in the individual, they add the disequilibrium emanating from ideas that can be unrelated. The knowledge that an individual presents a disequilibrium in his aversion of classical music AND a disequilibrium in his passion for ice cream tells us nothing. Someone who believes in Festinger’s theories might say "One shouldn't add apples and oranges." Festinger calculates the global rate of dissonance from a single cognition and those that are directly related to it. Our approach is situated between these two extremes. The use of a single knowledge structure on a restricted subject avoids comparing incompatible things (by making so we agree with Heider’s critics). Manipulating the knowledge structure as a whole allows us to compare indirectly related cognitions and in this sense we differ a little from Festinger’s approach.

Proposition 3: A knowledge structure can correspond to a schema of thought as defined in Festinger’s theory. Each item of the structure can be dissonant when compared to another item as long as a link can be drawn from one to the other.

Developing a methodology to perform cognitive dissonance measurement

According to Festinger (Festinger, 1957), if we wish to measure the amplitude of a dissonance we must take into account three factors:
1. If two cognitive elements are related, the relation between them is either dissonant or consonant.
2. The magnitude of the dissonance (or consonance) increases as the importance or value of the elements increases.
3. The total amount of dissonance that exists between two clusters of cognitive dissonance is in function of the weighted proportion of all related relations between the two clusters that are dissonant.

Therefore, if we wish to quantify the cognitive dissonance in a learner, we must take into account the importance of the elements of cognition that are in conflict. We must also consider the relationship between these two elements. If the two elements are weakly linked, the
amplitude of the dissonance must also be weak. There can not exist a dissonance between elements that have nothing in common. What Festinger’s theory does not indicate is exactly how does one calculate a value to measure dissonance.

In recent publications, several methods have been proposed. Vallerand (Vallerand, 1994) proposed a simple formula where the dissonance value is given by the sum of the dissonant cognitions divided by the sum of the cognitions (both dissonant and consonant). The total cognitive dissonance ($CD_{\text{total}}$) is therefore given by:

$$CD_{\text{total}} = \frac{\sum_{\text{dissonant\_cognitions}}}{\sum_{\text{consonant\_cognitions}} + \sum_{\text{dissonant\_cognitions}}}$$

In the realm of computer science, formulas giving a result between 0 and 1 are easy to use since the resulting value falls in a well-known range. For this reason, this formula is appealing. On the other hand, this formula does not take into account the importance that the individual associates to each cognition. Another, more complete, formula proposed by Joule in (Vallerand & Thill, 1993):

$$CD_{\text{total}} = \frac{\sum_{\text{importance \times dissonant\_cognitions}}}{\sum_{\text{importance \times consonant\_cognitions}}}$$

This time, the formula does take into account the importance that is associated to each cognition but no longer returns a values between 0 and 1. Neither of these two formulas is entirely satisfactory from the point of view of ITS since, neither the importance nor the nature of each cognition is known. How does one quantify what is happening in the mind of the student?

In experimental psychology, a researcher can evaluate different psychological parameters (including cognitive dissonance) in an individual or in a target public (the group to whom the course is destined). This can be done through interviews and by analyzing the results of questionnaires. Traditional methods, such as interviews, require both time and resources. As we will see later, identifying potential dissonant elements in a learner can help identify the important
points of a curriculum, the points where a strategy should focus. In particular, in the learning by disturbing strategy these critical points are those in which the troublemaker’s actions and arguments must be well developed. In fact these are the points which the learner may not acquire properly. It is normal that the domain expert emphasises these points.

The measure of cognitive dissonance, in conjunction with other measures, gives indications as to the amount of miscomprehension of the domain in an individual (which we compare roughly to a *measure of the entropy in ideas*). Learning knowledge as isolated fragments can lead to a poor comprehension of that knowledge. Brut test results do not give a clear measure of this problem.

Let us examine more closely the structure of the curriculum. Many different models of curricula have been developed to provide support to various ITS using them (see McCalla, 1990). The structures used vary in size and complexity. Although the method exposed hereafter can be adapted to be used with any structure (such as the concept network) we will use a model of the curriculum similar to the one proposed by Roger Nkambou (Nkambou, Lefebvre & Gauthier, 1996).

The network represented in figure 2 shows part of a curriculum that has been used to model the process of mammographs diagnosis in a radiology course. Students are taught how to order mammographs, to search for unusual features and to perform a diagnosis. For example $c_1$ corresponds to the capability "image rotation" and $c_8$ corresponds the capability "benign diagnosis". Since both prerequisite and contribution links can be found between $c_1$ and $c_8$, and since prerequisite links are weaker than contribution links, we can say that $c_1$ is a prerequisite to $c_8$. 
Figure 2. A curriculum for teaching radiology.

Transition nodes correspond to didactic resources. For example, T₁ regroups the demonstrations and the exercises specific to "images manipulation". Since our calculation will only considers capabilities, we will not discuss the transition nodes.

Since the structured representation of ideas in the curriculum corresponds to an "idealised" schema of thought, we suppose that it does not contain any contradictions, no cognitive dissonance. Analysing the results of the learner through a pre-test, using the curriculum as a reference, allows us to make inferences about the organisation of ideas in the learner's mind.

In order to reach our goal of calculating a value for cognitive dissonance, we must associate a numerical value to each node in the graph indicating its importance. There is no method which allows us to obtain the importance the learner attributes to each capability since he has not been in contact with them and especially because this is a subjective matter. The importance that the tutor associates to a capability while he gives a course can influence the importance that the student attributes to that capability. We can give the nodes values that represent the importance of the capability in the overall course. We suppose that this value reflects to some degree the value that a learner attributes to the capabilities. In order to do this we define the following function:

\[ I(c) = \text{importance of a capability.} \]
The values given will be between 0 (unimportant) and 1 (mandatory). An indication of the importance of a capability in the curriculum is the number of references made to that capability. Let us define now a function $d$ that gives the distance between two capabilities. This function must take into account the structure of the curriculum and the types of links that are used (this can vary from a curriculum model to another).

We can allow set some constraints on the calculation of $d$ in order to facilitate our further calculations:

- Each link type will have a numerical value of 1 or greater associated to it (see figures 2 for link types and values).
- If $c_1$ leads to $c_2$, then the distance $d$ is calculated as follows: for each possible path, find the greatest value between $c_1$ and $c_2$, and take the path the minimum value from the paths list.

The next step is to calculate the relatedness ($R$) between two cognitions. The basic cases are obvious: for two cognition which are completely unrelated, the function $R$ must give 0. The measure of relatedness is at its maximum when comparing a cognition to itself in which case $R$ returns 1:

$$R(c_1, c_2) = 0, \text{ if there exists no path from } c_1 \text{ to } c_2, \text{ and } ;$$
$$R(c_1, c_2) = \frac{1}{1 + d(c_1, c_2)}, \text{ otherwise.}$$

- This definition of $R$ respects the fact that relatedness is maximal when the distance is 0 (i.e. when one compares a cognition to itself).
- Since the curriculum is an oriented graph, in general $R(c_1, c_2) \neq R(c_2, c_1)$.
- The form of the formula $(1/x)$ insures that the function is limited; with our specific curriculum model, since there are only four types of links, the limits of the function are well known.

Figure 3 gives an example of a small curriculum network.
In this example, to calculate $d(c_1, c_7)$ we find three possible paths whose most costly links are 4, 4 and 3 respectively (see Figure 3). We therefore choose 3 as a value for the distance between $c_1$ and $c_7$ and the relatedness $R(c_1, c_7)=0.25$. This corresponds to the path $c_1, c_3, c_6, c_7$.

In order to justify this method we note the following:

1. The number of links between two capabilities depends on the granularity of the curriculum and so summing the values along a path is not a viable solution.
2. The weakest link in a chain represents its overall strength. For example, if in a chain we find even one link of preferred prerequisite then we know that the relationship between the capabilities is weak.
3. In all the possible paths, choosing the most advantageous consists of choosing the one with the highest relatedness.

According to cognitive dissonance theory, cognitive dissonance can occur whenever two cognitions, beliefs or behaviors related to the same cognitive schema are in conflict. In the case of the curriculum, we can detect a dissonance if the learner has correctly answered a question on capability $c_1$ but has also incorrectly answered another question on $c_1$ or on $c_2$ which is prerequisite to $c_1$. In other cases it is not possible to detect dissonance. We can not for example detect apparent consonance. An apparent consonance can occur when the learner errrs on two questions both related to capability $c$ even though both errors were due to dissonant beliefs.

To give a concrete example let us suppose that the learner answers a questionnaire on elementary physics. The questions are true or false. The student successfully answers: "There is air on the surface of the Moon. (False)" and "You can hear an explosion on the surface of the

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1 One can also see this as a hidden dissonance.
Moon. (False)". There seems to be consonance between these results since the student has succeeded in answering two questions related to the same capability. Despite this, if the learner had answered the first question correctly because he knows that there is no air on the Moon, but answered the second false because he believes that there can only be explosions on Earth, then perhaps there is dissonance. Perhaps the student believes that sound can travel without the support of air, and this dissonance has not been detected.

The calculation of the potential dissonance between two capabilities is a function that takes into account both the importance of the capabilities and their relatedness. The function $CD_{pot}$ is calculated as follows (with a $\max$ function since we wish to obtain the maximum dissonance possible):

$$CD_{pot}(c_1, c_2) = \max(I(c_1), I(c_2)) \times R(c_1, c_2)$$

The questionnaire can take many forms (true or false, multiple-choice, associative, etc.). In order to simplify the calculation we will suppose that each question is a "true or false" question. The results are easier to analyse than for multiple-choice or associative questions. Each question is taken from one or more elements from the curriculum. Let $Q$ be the set of questions. The relation $S_c$ gives for a question $q$ its corresponding capability in the curriculum:

$$S_c(q) = c ;$$

Let $V(q)$ be the result of the question from a given learner (0 = failed; 1 = succeeded). If two questions $q_1$ and $q_2$ are related (the relatedness between their two associated capabilities is not 0), then the success difference $D$ is a non-symmetric function defined as:

$$D(q_1, q_2) = \max(V(q_2) - V(q_1), 0).$$

If no relation can be found between the two questions, then:

$$D(q_1, q_2) = 0.$$
We consider that there is possibly a cognitive dissonance when a question has been successfully answered while a prerequisite to that question (or to a question related to the same capability) has not. The success difference function is therefore not symmetrical. This function would become more complicated if one considers multiple choice questions. Multiple choice questions are often related to multiple capabilities and thus when the learner fails such a question the diagnosis can be very complex. Nevertheless, analysing these results would be a great achievement; developing a methodology to do so would be, in our opinion, and interesting field of research.

If we wish to calculate the total dissonance in a learner, within the framework of the capabilities of a curriculum, we can use the following formula:

\[
CD_{\text{total}} = \frac{\sum [D(q_1, q_2) \times CD_{\text{pot}} (S_c(q_1), S_c(q_2))]}{\sum CD_{\text{pot}} (S_c(q_1), S_c(q_2))}.
\]

If we wish to calculate the cognitive dissonance for a given capability in a learner we can use the following formula:

\[
CD_{\text{capability}} (c) = \frac{\sum [D(q_1, q_2) \times CD_{\text{pot}} (S_c(q_1), c)]}{\sum CD_{\text{pot}} (S_c(q_2), c)}.
\]

\(CD_{\text{capability}}\) gives, for each capability in the curriculum, a measure of the quantity of cognitive dissonance associated to that capability. This calculation takes into account the links existing between the particular capability and all other capabilities. In addition it considers by pair all the questions which are related to that capability. A high value indicates that the capability is likely to be misunderstood by that individual. Because of this, it becomes important to develop the interventions of the pedagogical actors (tutor, troublemaker, etc) in these critical points of the curriculum. Identification of these critical points accelerates the development of the curriculum by allowing the expert to concentrate the development effort in key areas.
Application to an ITS in the medical domain

The task we are modelling is medical diagnosis, more specifically the diverse illnesses affecting breasts. The central element is a set of four mammographs. We have chosen relatively simple cases where the student needs to consult the medical history of the patient, but where the breast radiographs can present no more than one pathology.

The exercise is divided into four parts:
1. Ordering the mammographs: by using a series of image manipulation tools (found on the toolbar), the student must place the four mammographs in the correct order and must orient them properly. The orientation of the radiographs supposes that the student can manipulate the images by rotating them or flipping them both horizontally and vertically;
2. Identification of critical regions: the learner traces the contour of regions of interest for the diagnostic of the pathology;
3. Region characterisation: at any times, the student may select a region and associate a feature from the features list to it;
4. Choice of diagnosis: the student chooses the diagnosis that he wishes to propose from the left-hand list in an order that indicates their relative importance and sends these items to the right-hand list. He can also remove an item from the right-hand list.

The system is composed of a window containing the four mammographs, the list of possible features and a list of possible diagnostics. The two actors, the tutor and the troublemaker, have each their own dedicated window so that they be well dissociated from the exercise. These two actors cooperate in their teaching task by planning their interventions; each intervention is negotiated with the other actor in order to create for the learner a pedagogical environment that is dynamic and stimulating.

The tutor presents each exercise and makes comments so as to guide the student in the resolution of the exercise. He can correct the learner in either a weak manner, by telling him that an error was committed and letting him correct it by himself, or in a strong manner, by correcting
the error and presenting the solution to the student. The troublemaker is free to intervene at any moment to give advice (either correct or incorrect). The tutor can ask for a consensus between the learner and the troublemaker. Figure 4 shows a glimpse of the system, at the beginning of an exercise.

Figure 4. System interface.
Using the formulas to infer cognitive dissonance in a student

The curriculum for the radiology course was presented in figure 2. In order to show an application of formulas (see tables below) used to calculate dissonance, we have used simulated students to obtain results for a questionnaire of 20 questions on this curriculum. In the case shown in Table 1, the score of the learner is 60%. It is important to note that as the score reaches 50% it is easier to detect dissonance (see figures 5, 6 and 7). If the score is too high or too low, consonance appears more often. Table 1 shows the questions, the corresponding capabilities and the results.

Table 1
Pre-test results.

<table>
<thead>
<tr>
<th>Question</th>
<th>Capability</th>
<th>Result</th>
<th>Question</th>
<th>Capability</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>q1</td>
<td>c1</td>
<td>1</td>
<td>q11</td>
<td>c6</td>
<td>1</td>
</tr>
<tr>
<td>q2</td>
<td>c1</td>
<td>1</td>
<td>q12</td>
<td>c6</td>
<td>0</td>
</tr>
<tr>
<td>q3</td>
<td>c2</td>
<td>1</td>
<td>q13</td>
<td>c7</td>
<td>1</td>
</tr>
<tr>
<td>q4</td>
<td>c2</td>
<td>0</td>
<td>q14</td>
<td>c7</td>
<td>0</td>
</tr>
<tr>
<td>q5</td>
<td>c3</td>
<td>0</td>
<td>q15</td>
<td>c8</td>
<td>0</td>
</tr>
<tr>
<td>q6</td>
<td>c3</td>
<td>1</td>
<td>q16</td>
<td>c8</td>
<td>1</td>
</tr>
<tr>
<td>q7</td>
<td>c4</td>
<td>1</td>
<td>q17</td>
<td>c9</td>
<td>1</td>
</tr>
<tr>
<td>q8</td>
<td>c4</td>
<td>1</td>
<td>q18</td>
<td>c9</td>
<td>0</td>
</tr>
<tr>
<td>q9</td>
<td>c5</td>
<td>0</td>
<td>q19</td>
<td>c10</td>
<td>1</td>
</tr>
<tr>
<td>q10</td>
<td>c5</td>
<td>0</td>
<td>q20</td>
<td>c10</td>
<td>1</td>
</tr>
</tbody>
</table>

Using the curriculum network, we fill out a table of relatedness (table 2) for each couple of capabilities. For example, for the capabilities c_1 and c_8 we obtain two possible paths. The first is $c_1 \rightarrow T_1 \rightarrow c_4 \rightarrow T_3 \rightarrow c_8$ and its worst link has a value of 1. The second is $c_1 \rightarrow T_1 \rightarrow c_4 \rightarrow T_4 \rightarrow c_8$ and its worst link has a value of 3. We therefore choose the first path. In this case $R(c_1, c_8) = \frac{1}{1+1} = 0.5$. 


The calculation of cognitive dissonance gives a value of $CD_{\text{total}}(i)=0.252743$, which is an average value. If we study in detail the results of the pre-test, we can see that for six out of ten capabilities there is a strong difference between the results of corresponding questions and therefore, a possibly strong cognitive dissonance. We can calculate the cognitive dissonance for each capability for this learner:

Table 3
Cognitive dissonance values for each of the capabilities of the curriculum.

<table>
<thead>
<tr>
<th>capability</th>
<th>$CD_{\text{capability}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>c1</td>
<td>0</td>
</tr>
<tr>
<td>c2</td>
<td>0.5</td>
</tr>
<tr>
<td>c3</td>
<td>0.5</td>
</tr>
<tr>
<td>c4</td>
<td>0.25</td>
</tr>
<tr>
<td>c5</td>
<td>0</td>
</tr>
<tr>
<td>c6</td>
<td>0.5</td>
</tr>
<tr>
<td>c7</td>
<td>0.4167</td>
</tr>
<tr>
<td>c8</td>
<td>0.2325</td>
</tr>
<tr>
<td>c9</td>
<td>0.2222</td>
</tr>
<tr>
<td>c10</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 3 shows that this individual is likely to misunderstand the capabilities $c_2, c_3, c_6,$ and $c_7$. The expert, conscious of these results, must develop more carefully the interventions of the actors for these capabilities. The material from the course must also emphasise these capabilities in addition to the questions erroneously answered by the learner. Combining these results with the pre-test results and other statistical analysis, the expert can better predict the needs and the behaviour of the student when faced with this learning material.

**Analysing the $CD_{\text{total}}$ formula with a probabilistic approach**

To study the behaviour of the formula that allows the calculation of $CD_{\text{total}}$, we have generated 3500 results such as those found in table 1. We have used a uniform rule to generate the total score (on 20). The goal of this exercise was to verify several hypotheses which, while they intuitively seem to be true, must be verified more rigorously:

- for scores of 0 or 20 it is not possible to detect cognitive dissonance, and so $CD_{\text{total}}$ should always be 0
- as the score tends towards 50%, it should be possible to detect more cognitive dissonance. A greater confidence should be accorded to the results of the formula in these circumstances.
- finally, the structure of the curriculum assures that in certain key situations, $CD_{\text{total}}$ has either a null or a very high value. These special cases are predictable, and should always be pedagogically explainable.

Figure 5 shows for each of the 20 possible scores, the distribution of the 175 values of $CD_{\text{total}}$. First we notice that as the score approach 10/20 (50%) the dispersion is greater and the values of $CD_{\text{total}}$ tend to be higher (as shown by the correlation curve, polynomial of fourth degree). The peak is situated between 9 and 10, the scores from which more cognitive dissonance can be detected. This is coherent with our starting hypothesis.
Two points seem particularly important to mention. The first is at (10,0) and corresponds to a situation where the learner has a score of 10/20 but a cognitive dissonance of 0. The second, situated at (4, 0.52), corresponds to a situation where the low score would normally stop us from determining the mental confusion but where the value of $CD_{\text{total}}$ is remarkably high. This special case can happen if a student answers successfully four of the questions about the most complex capabilities, but fails all of the basic ones. This could indicate a high level of confusion in the student's mind.

The graph in figure 6 shows that for scores close to 10/20 the average total cognitive dissonance is higher. This corresponds to the hypothesis that a greater part of cognitive dissonance is detected when the brut score nears 50%. On the other hand, when the score tends to 0 the situation becomes problematic: does the score indicate a lack of knowledge or of comprehension? An important (yet intuitive) conclusion that we come to when analysing this curve: pre-tests should be neither too difficult nor too easy.
Figure 6. Mean for each score (for 3500 uniform random score sheets).

Figure 7 shows that not all of the possible pre-test scores are equally precise in the detection of cognitive dissonance. Low to average scores present a high variability which denotes a great richness in results. Often such scores denote very symptomatic tendencies: a learner who has not properly assimilated a key concept or who has not well synthesised the material. It is possible to present a score of 10/20 and to present no cognitive dissonance. For example, a student could remember everything from the first half of a lesson, and nothing from the second half (maybe she fell asleep?). If she understood everything she remembers, then she finds herself in that particular case.
Conclusion

We have shown in this article that it is possible to quantify the total cognitive dissonance in a learner. We have also shown that it is possible to give an indication of the cognitive dissonance for a given capability of the curriculum. The results from this calculation serve to plan external conflicts (between the learner and a troublemaker) in order to make the student aware of the incoherences in his ideas.

In this article co-operation in teaching comes from the efforts of two simulated tutors, one specialized in the transmission of knowledge (the tutor), the other in a pedagogical aspect of this transmission (the troublemaker).

The troublemaker plays the role of a learner following the same course as the real student. The troublemaker strategy allows us to separate the transmission of knowledge from its reinforcement. This allows the student to maintain a high level of confidence in the tutor even though the credibility of the troublemaker may diminish.
The troublemaker helps the learners become aware of the incoherence in their ideas and to correct them. This were not possible if we did not have means for evaluating the internal conflict in the learner. The method presented in this article to calculate cognitive dissonance explores in more depth what has not been previously reached. What distinguishes it from the formulas proposed by Festinger and his successors is the use of a knowledge structure as basic means (in our case, the curriculum). This allows us to complete more complex calculations than the mere comparison of two cognitions. Despite its uneven performance, we believe that the formula presented in this article is a reliable indicator of the rate of cognitive dissonance in an individual, since we studied its behaviour with a probabilistic approach.

Certain questions remain: how can we ensure that the curriculum used is free of contradictions? In science, is it valid to assume that there is only one way of organising the material (perhaps we have a more epistemological question here)? How can we ensure that the pre-test is a good representation of the curriculum? What importance does the indicator of cognitive dissonance should have in the evaluation of the learner?

The method presented in this article was developed as part of a project that aims at providing field experts with tools to adapt a course to a given target population. The characterization of the target population involves several aspects, which include both affective (preferences as to teaching style, course presentation mode, etc.) and cognitive criteria (knowledge well acquired, evaluation of cognitive dissonance, missing knowledge). We have successfully implemented a troublemaker in a small scale tutoring system, and we plan to test it on a larger scale in the near future.

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References


