Interpreting relations between learning and using materials

André Tricot
South Pyrenees University for Teachers' Education, Toulouse, France

Abstract

A context in which learning is required can be generally described as connecting: A learning goal consisting of new knowledge to be acquired; materials used to assist the learner in acquiring knowledge such as texts, diagrams or hardware; tasks in which the materials are processed such as reading, solving a problem or manipulating an object; students and their characteristics. Many instructional designs are based on the assumption that if a student succeeds in processing the material then the learning goal will have been achieved. Research on cognitive load theory has indicated that this relation is more complex. Sometimes, processing materials is so cognitively costly that the learning goal is not reached. It may be possible to learn without some types of processing while at other times, as found in a recent study, some types of processing may be essential for learning. In this paper, the various, possible logical relations between attaining a learning goal and the task of processing learning materials are analysed. This logical framework can be used to interpret empirical results from experiments conducted within a cognitive load framework.

Generally, designers of learning materials attempt to design or formulate texts, pictures, objects or instructions while also addressing other considerations in order to ensure that learners succeed in processing the material and learning, i.e. acquiring the intended knowledge. The cognitive load theory (CLT) has made a major contribution in demonstrating that the processing of the material sometimes has too great a cognitive cost for learners with the result that the intended learning does not take place. At times, thus, the processing of the learning material seems to compete with learning. These studies have also shown how we can design learning materials whose processing imposes a lower cognitive cost. Usually, such improvements in the material result in enhanced learning. However, recent studies (Kalyuga, Ayres, Chandler & Sweller, 2003) have shown that improving materials for novice learners can result in an increase in processing difficulty when these learners reach a more advanced level of expertise. While this reversal effect appears to apply to the processing of the material, we are as yet unaware of its effect on the acquisition of new knowledge since it is difficult to compare the acquisition of new knowledge in novice learners and experts. Studies of cognitive load together with a large body of other research have thus shown that there may be a variety of relations between the processing of the material and learning. In this article, we put forward a logical description of these different relations. We propose a logical framework for the interpretation of the associations between performance in using such material and learning performance. We illustrate this framework by reporting an experiment involving the use of a dictionary to learn the definition of new words. This allows us to consider that there may be testable hypotheses concerning the relation between the use of learning materials and learning itself. Thus, the CLT could be considered to be a refutable theory of relevance in the learning field.

The different relations between attaining a learning goal and processing learning materials

Self-referential and specific learning situations

In their classic article entitled "The theory of learning by doing", Anzaï and Simon (1979) present an analysis of a protocol for the solution of the Hanoi tower problem. According to Anzaï and Simon, subjects learn to solve this problem by adopting a trial-and-error approach to it. One might say that, for these authors, the learning situation is self-referential. It is itself the aim of learning. Anzaï and Simon's analysis of this protocol allows them to describe in greater detail what it is that subject learns when she learns. She learns to transform the states of a situation, transform a strategy and, ultimately, she learns the structure of the problem, i.e. a set of relevant, effective productions.

It is therefore possible to describe Anzaï and Simon's theory from two different points of view. According to the first of these, subjects learn to perform task T by doing task T. This is a self-reference. According to the second viewpoint, doing task T endows subjects with knowledge K. This relation could be one of implication the nature of which is unknown to us. The authors do not say whether this knowledge K enables subjects to do anything other than perform task T.

In everyday life, it is often useful to have a self-referential view of learning. We learn to drive a car in order to drive a car and we know how to type because we have learned to type by typing. Most of the time we do not represent this learning to ourselves as corresponding to the acquisition of knowledge K which may be transferable. We know how to drive a car and that is all.

The self-referential viewpoint is also highly relevant in professional life. For example, Myles-Worsley, Johnston and Simons (1988) conducted experiments involving perception and recognition within the field of X-ray diagnosis. Their work consisted of comparing this activity as a function of the expertise of the doctors (university undergraduates, first year in-house radiologists, junior staff radiologists and senior radiologists). The performances of the experts were much better than those of the other subjects in a task requiring the identification of X-rays of lungs affected by a lesion whereas their performance was inferior to that of the other subjects when tested with X-rays of healthy lungs. This difference in performance in a recognition task was measured on the basis of very short processing times (500 ms). The authors controlled for the recognition capabilities of these different subject populations by means of a face recognition task in which the different groups all achieved equivalent performance levels. In other words, expert radiologists are able to detect lesions very quickly in an X-ray and are able to recognize these X-ray images but this skill is not transferable. What is more, it is accompanied by some form of specific loss of ability in the processing of X-ray images of healthy lungs. How did they acquire this perceptual ability? By practising. We can therefore consider certain types of knowledge K as being sub-components of a general professional ability. In this particular case, the ability to perceive and recognize X-rays depicting lungs affected by a lesion is a sub-component of the ability to perform X-ray diagnoses. This perceptual ability, which we term knowledge K, is acquired through practice, through the repeated mobilization of this knowledge K, and it is not transferable. It is therefore specific. Furthermore, it is accompanied by the inhibition of certain other types of processing, in this case the processing of X-rays of healthy tissue. Finally, the authors do not mention the possibility of a radiologist practising this task without acquiring this knowledge K or acquiring this knowledge K without practice.

We can see that learning can be described as establishing a relation between the knowledge to be acquired (K) and the task in which materials are processed (T). It would appear that different relations between K and T are possible.

To summarize:

(1) Some learning is self-referential. To learn to perform task T is the same as performing task T.

(2) Some learning is specific. The acquisition of knowledge K requires the (repeated) performance of task T; however, K does not make it possible to do anything other than perform task T. From a logical point of view, the repetition of T and the acquisition of K are equivalent.

We believe that it is important to stress that some self-referential learning is only so when considered from a particular viewpoint, given a certain mode of practice and for certain subjects. One and the same type of learning can be interpreted differently depending on the conditions under which it is performed. For example, the learning of a word processing program necessarily requires the use of the tool itself. It is a priori self-referential. However, Sander and Richard (1997) have shown that if subjects already know how to type then a transfer analysis indicates a very different learning process. Subjects who already know how to type spontaneously consider the word processor to be a rather sophisticated typewriter and therefore consider the activity to be the same. However, this transfer involves certain problems. Since there is only a partial analogy between the two objects, it causes subjects to commit certain errors of manipulation while simultaneously inhibiting a number of possible actions. Sander and Richard have shown that recourse to abstractions is effective. To consider not typewriting but writing or even manipulating an object as the reference activity results in better learning.

Situations in which performance of the task involves learning

In a study of classic transformation problems, Pierce, Duncan, Gholsn, Ray and Kambi (1993) showed that knowledge K acquired during the performance of task T can be re-used in a task T' which is non-isomorphic to the task T. For example, the authors showed that subjects who successfully completed a Cannibals and Missionaries task can transfer the acquired knowledge to a Jealous Husbands task if they are permitted to freely explore the problem space with little emphasis on goal attainment. They use cognitive load theory (Sweller, 1988, 1989) to explain these results.

This approach to the Cannibals and Missionaries task should produce a higher quality base schema than constrained exploration that emphasizes goal attainment. This result can be described as follows. By performing task T in free exploration conditions, subjects acquire knowledge K which can be re-used to perform task T'. It therefore appears that, in this case, acquiring K (in such a manner that K is transferable) requires T to be performed by means of free exploration. In this experiment, it is very interesting to note that subjects achieved better success levels on T if they were not left to explore the problem space freely but were guided in their exploration. Thus if we continue to apply the self-referential viewpoint presented above then we can state that when subjects are guided in their completion of task T then they learn to complete task T effectively. However, in this condition, the acquired knowledge K is less readily transferable to a task T' than when T is performed on the basis of free exploration. It is clearly possible that there are many other tasks T'' that permit the acquisition of the knowledge K. However, in this experiment it is not clear whether it is possible to succeed in T' after failing to complete T since all the subjects were successful in T.

To summarize:

(3) In the case of some learning, if and only if task T is performed in a certain way (for example, free exploration), then success in task T implies acquisition of the knowledge K and success in the task T' (which is analogous to task T) implies acquisition of knowledge K.

(4) In the case of some learning, if and only if task T is performed in a certain way (for example, guided exploration), then the learning is specific (2), that is to say that there is a relation of equivalence between success in T and the acquisition of K.

Research into CLT has made it possible to identify the various ways in which the performance of T results in the acquisition of the transferable knowledge K. For example, Paas (1992) has shown that the acquisition of transferable knowledge in the statistical domain might be more effective when worked examples and completion problems are used than when traditional problem-solving techniques are employed. The same result has been obtained by many researchers working in a variety of learning fields (see Sweller, van Merrienboer & Paas, 1998, for a review). These studies thus show that while there are various possible relations between K and T, in particular as a function of the way T is performed, then the way the learner accomplishes T may depend on the way in which T is presented.

Indeed, studies of CLT have revealed that the way the material is presented may influence task performance and learning. In particular, these studies have demonstrated the link between the presentation of the material and the split attention effect. The split attention effect is observed when subjects have to process multiple sources of information which they have to integrate at a mental level in order to be able to infer the meaning from the presented material. For example, in the case of geometry, subjects have to divide their attention between the processing of the presented shape, on the one hand, and the text relating to this shape on the other. Subjects cannot understand the presented material unless they mentally integrate disparate sources of information. CLT has been used to suggest that the process of split attention, as well as the mental integration of the material, are cognitively costly due to the ways in which the information has traditionally been presented and structured. Numerous studies (see e.g. Sweller & Chandler, 1994) have shown that the physical integration of the sources of information, for example by placing the written notes on the corresponding points of the geometrical shape rather than next to it eliminates the negative effects of split attention. We can therefore state that in many cases, performing T requires the processing of materials and that simplifying the processing of these materials increases the probability that subjects will complete the task successfully and learn (acquisition of knowledge K).

To summarize:

(5) In some cases, if the successful completion of task T implies the acquisition of knowledge K and if accomplishment of task T implies the processing of material M then facilitating the processing of M is conducive to the acquisition of knowledge K.

If the elimination of the split attention effect improves learning by reducing the working memory load, Mousavi, Low and Sweller (1995) have suggested that a similar positive effect can be obtained by increasing the size of useful working memory. These authors suggest that in order to achieve this type of goal, it is necessary to use dual mode didactic presentations, i.e. presentations in which the different sources of information that have to be integrated are presented in different sensory modes (auditory and visual). They demonstrated that a geometrical shape is learned better when it is presented visually and accompanied by a spoken commentary than when it is presented in a conventional way (text and shape presented visually). Moussavi et al. (1995) have also shown that this dual mode presentation effect is only observed when the material is difficult to process, i.e. when it causes a high cognitive load due to the large number of points in the shape that are referred to in the text. The authors describe this type of situation as being highly interactive. In contrast, in the case of low interaction shapes only a small number of points are referred to in the text.

To summarize:

(6) In some cases, if successful completion of task T implies the acquisition of knowledge K and if the accomplishment of task T requires the processing of material M which involve a high level of interaction then simplifying the processing of M by intermixing the auditory and visual modes contributes to the acquisition of the knowledge K.

Situations in which learning implies success in the task

Research into CLT has revealed something which, though apparently self-evident, is nevertheless a very important aspect of studies of learning. When task accomplishment or the processing of the material are too cognitively costly in a learning situation, nothing is learned. For example, Tuovinen and Sweller (1999) compared the performances of two working groups of students who had been asked to design a database. The two groups attended the same course. However, following this, the first group was placed in a learning-by-discovery scenario whereas the second group continued to learn on the basis of worked examples. The students in the first group had to solve problems, which were primarily practical in nature and which they set themselves, whereas the members of the second group followed a predefined programme involving the study of problems which had already been solved. In both groups, half of the students were novices in the database field whereas the other half already had a little knowledge of the subject. The results indicated that novices in the database field found a discovery-based approach to performing the learning task too difficult. Their scores in the knowledge test at the end of the learning phase were extremely low and did not even attain half of the mean scores for the other three subgroups. It seems as if the novice subjects learned nothing or almost nothing during three consecutive learning-by-discovery sessions.

Overall, these results show that, in certain cases, the acquisition of knowledge K implies success in task T. However, these cases are often difficult to distinguish from cases in which there is an equivalence relation between success in task T ands the acquisition of K. From a logical viewpoint, the difference lies in the possible existence of a certain number of subjects who took part in the experiment and who succeeded in T without acquiring K. If such subjects exist, we can describe the learning situation in terms of an implication from K towards T. If no such subjects exist then the relation between success in T and the acquisition of K is one of equivalence.

To summarize:

(7) In certain cases, the acquisition of the knowledge K implies success in the task T.

Learning situations which cause problems of interpretation

Research into CLT has recently given rise to a set of important results concerning the effect of the subjects' expertise. These results will allow us to address a problem concerning the description of learning situations and the interpretation of data in experiments of novice – expert type which involve learning tasks. Initially, the effect of the subjects' expertise on the cognitive load is very simple. The more expertise a subject possesses in a field then the less cognitively costly the processing of a situation pertaining to this field is. Kalyuga, Chandler and Sweller (1998) have shown that in subjects who have been given a significant volume of instruction in a particular field, the split attention effect is neither eliminated nor even reduced by the use of text/image integration techniques. When these subjects are compared with novice subjects on the same tasks in two conditions employing classic material and integrated material, it becomes clear that in fact it is not so much the case that the split attention effect is not eliminated in the integrated material condition. Instead, they find that, in these subjects, there is no or only a small split attention effect in the classic material condition (or at least they experience no difficulty in processing disparate sources of information). However, the experiments reported in the Kalyuga et al. article did not measure the effects on learning of the presentation format used for the material or the subjects' level of expertise. Instead, they measured the effects of expertise and presentation format on fault-finding tasks or multiple choice items in Experiment 2 and the effect of presentation format on learning in Experiment 3.

The redundancy effect interacts strongly with the effect of the subjects' expertise. At first sight, the effect of the redundancy of the material appears to be easy to account for. When redundant material or the same information is presented several times in different forms (for example, in textual and pictorial form) then the cognitive load is greater (and performances worse) than when the same material is presented without redundancy (e.g. Sweller & Chandler, 1994). The difference between the split attention effect and the redundancy effect lies in the fact that the split attention effect occurs when the sources of information cannot be understood in isolation whereas the redundancy effect occurs in cases where it is possible to understand the information sources in isolation. Here again, the occurrence of these effects is very highly related to the subjects' expertise. Kalyuga, Chandler and Sweller (1998) explicitly state that everything suggests that identical material which is considered integrated in the case of novice subjects and has a positive effect on their performances may be considered redundant for expert subjects, thus resulting in a negative effect on performance. In the series of experiments referred to by Kalyuga, Ayres, Chandler and Sweller (2003), who demonstrate a reversal of the majority of the effects as a function of subjects' expertise, there is, we believe, no comparison between what can be acquired by novice and expert subjects. This is because, when required to learn something, knowledgeable subjects cannot be compared with less knowledgeable ones since they do not have to learn the same things. Only a protocol in which performance is measured in terms of the difference between post-test and pre-test values might make it possible to conduct such a comparison. It is conceivable that in some cases, subjects who are already experts have nothing to learn since the knowledge K has already been acquired by them. In other words, even certain protocols involving the subtraction of post-test from pre-test values might prove inoperative if the experts obtain excessively high pre-test scores. We could then hypothesize that the reversal effect as a function of expertise applies to the completion of task T, and in particular the processing of the materials M of which it consists, but not the acquisition of knowledge K. It might be possible to extend the results relating to completion of task T to the acquisition of knowledge K if the equivalence between these two can be demonstrated in advance in subjects possessing different levels of expertise. A priori, we consider that such an equivalence would be very difficult to demonstrate. This is because, in fact, the reversal effect suggests that facilitation is ineffective with subjects who are experts in the use of the material, but does not contradict the fact that successful use of the material (success in the task + processing of the material) implies learning (or vice versa) since experts and novices do not have the same things to learn. The learning situation (which has to take account of the knowledge to be acquired and existing knowledge) is not comparable in the cases mentioned here. Learners who do not have to learn the same things cannot be compared on the basis of their learning.

To summarize:

(8) In the case of novice subjects, the mechanisms of integration, redundancy and audio-visual fusion facilitate the processing of interactive material and this facilitation improves learning.

(9) In the case of expert subjects, the mechanisms of integration, redundancy and audio-visual fusion impair the processing of interactive material, but we are unaware of the consequences for the acquisition of new knowledge.

Implicit learning, adaptation and their interpretation

The literature to which we have referred in the last part of this article relates to specific learning situations. In particular it concerns explicit learning requiring action and primarily conducted within a framework of instructional guidance. Such learning is based on the performance of a task which the subjects know they are performing and the processing of materials which the subjects know they are processing. Clearly, human learning cannot be reduced just to this type of explicit learning. Some learning is implicit (Berry, 1997) and does not involve the conscious completion of a task. Some learning, such as the learning of grapheme-to-phoneme correspondence in reading, may be achieved explicitly by some subjects and implicitly by others (Cunningham, 1990). Furthermore, the psychology of reading has studied the nature of the relation between phonological awareness (an explicit type of knowledge) and learning to read (e.g. Perfetti, Beck, Bell & Hughes, 1987). Is this or is it not an implication relation? Two avenues of investigation have been followed to study this question. Can one of these competences be present while the other is absent (in which case it would be possible to define the direction and nature of the implication, or even its independence)? Is training in one accompanied by the acquisition of the other? Thus, the existence of explicit and implicit learning is not only proven, but it also seems that they may both be possible for identical items of knowledge for acquisition. However, it is most specifically the relations, and in particular the implication relations, between knowledge, tasks and learning that have been studied in a wide variety of fields. Other types of learning strongly resemble a process of human adaptation to the environment (Anderson, 1990).

To summarize:

(10) It may be possible to learn without certain types of processing as in the case of the explicit accomplishment of a task or the processing of learning material.

The problem underlying the design of a learning situation that makes it possible to attain a given learning goal, that is to say ensures the acquisition of certain new knowledge by a learner, therefore involves the relevance of the task and material in the light of the knowledge possessed by the learner. The proposal set out below seeks to describe how this relevance may be evaluated.

A logical framework to describe relations between attaining a learning goal and processing learning materials

Above, we have stressed that the knowledge that is to be acquired in an explicit learning situation is relative to the situation (task and materials) and the subjects' prior knowledge. Various relations are possible between the accomplishment of the task, and in particular the processing of the material of which it consists, and the knowledge that is to be acquired. Thus we can state that any explicit learning situation can be described as a relationship between at least four terms: The knowledge to be acquired, the task to be performed, the material to be processed and the learner (his or her characteristics, in particular in terms of prior knowledge). We have shown that the relation between the processing of the material and the acquisition of the intended knowledge may differ in nature but that, whatever the circumstances, it is rarely direct. Thus, we believe we have been able to draw attention to the fact that the interpretation of certain recent results relating to CLT needs to be considered with some caution since certain effects on the processing of the material cannot be thought of as directly improving or impairing performance. This caution can be observed in the work conducted by Kalyuga and co-workers.

We believe that the evaluation of the relevance of a learning situation and the results it yields requires the description of the relation between the processing of the material and the intended learning. This proposition implies that we are able to interpret the links between the variables that measure the processing of the learning material and those that measure the acquisition of the intended knowledge. Tricot and Tricot (2000) recently attempted to address this problem. For practical reasons, we shall consider that success in the task and the processing of the material can be described together under the term "successful use of the learning material". This approach considers that it is initially possible to evaluate the use of the material and the acquisition of the intended knowledge on the basis of binary variables: UM (success/failure) for the use of the material and AK (success/failure) for the acquisition of the intended knowledge, i.e. the learning. In logic, the relations between two binary variables can be described using a truth table. This furnishes a logical interpretation of the nature of the relation. For example, in Table 1 (in which the acquisition of knowledge K is represented by AK_1 and non-acquisition by AK_0, and the successful use of the material by UM_1 and unsuccessful use by UM_0), the second column corresponds to an "inclusive OR" (represented by $\vee$). This column describes learning material that learners may succeed in using whether or not they acquire the knowledge K, or that learners may fail to process even though they acquire the knowledge K.

Insert table 1 about here

If we collect a set of observations of learners who are using learning material in order to learn something then we can describe the frequencies f of the co-occurrences of the states of UM and AK in a contingency table (see Table 2). The sum of the frequencies is equal to 1.

Insert table 2 about here

The implicative analysis (Bernard, 1999) makes it possible to describe the logical relation between these two variables on the basis of the frequencies distribution in this contingency table. To do this, it is necessary to consider a 2x2 contingency table as a column in a truth table where frequencies equal to 0 correspond to false (or impossible) states and frequencies greater than 0 to true (or possible) states. In the Tricot and Tricot model (2000), the authors consider that the sum (= 1) of the frequencies greater than 0 corresponds to a uniform distribution of these frequencies (see Table 3).

Insert table 3 about here

Below are the interpretation of the links between these two variables.

Inclusive OR, $AK_1 \vee UM_1$. Material not particularly specific (neither necessary nor sufficient) to the intended learning.

Implication $AK_1 \Rightarrow UM_1$. Material sufficient but not necessary for the intended learning.

Independence, UM_1, $\forall$ AK. Material can be used but is only moderately useful for the intended learning.

Implication $UM_1 \Rightarrow AK_1$. Material necessary but not sufficient for the intended learning.

Independence, AK_1, $\forall$ UM. Placebo material for the intended learning.

Equivalence $AK_1 \Leftrightarrow UM_1$. Material specific (necessary and sufficient) for the intended learning.

Conjunction $AK_1 \wedge UM_1$. Material perfect, useable and useful for the intended learning.

NAND (not And), UM_1 / AK_1. Incompatibility. Material hinders the intended learning.

Exclusive OR, UM_1 w AK_1. Material hinders the intended learning.

Independence, AK_0, $\forall$ UM Material useless for the intended learning even though moderately useable.

Implication $AK_0 \Rightarrow UM_1$. Material is useable but useless for the intended learning.

Independence, UM_0, $\forall$ AK. Material unusable for the intended learning.

Implication $AK_1 \Rightarrow UM_0$. Material paradoxical.

NOR (not Or) $AK_1 \downarrow UM_1$. Material bad or unsuitable for the intended learning.

Tautology. All the relations between use and learning are true.

Application: Using and learning with an encyclopaedic dictionary between ages 8 and 11

To illustrate the links between learning and the use of material, we performed an experiment involving children in Cycle III (in France, this corresponds to the last three years of primary school, the children being 8 years old at the start of the first year and 11 years old at the end of the third year). More precisely, our aim was to demonstrate the various possible relations between learning and the use of an item of material that is frequently present in the school environment. We asked pupils in Cycle III to write down word definitions either with or without the aid of an encyclopaedic dictionary. The words in question were either known to the pupils (in which case, the dictionary was, a priori, of little use to them since there was nothing to learn), or unknown to them (in which case, the dictionary was, a priori, useful to them since there were words to learn). Two versions of the same dictionary were used: A paper version and an electronic version (either one or the other for each pupil). We made the following hypotheses concerning the nature of the relation between the two variables. At the start of Cycle III the provided encyclopaedic dictionary would be unusable (the pupils have not yet learnt to use it) and the pupils should therefore learn nothing. The distribution of performances should therefore correspond to "unsuitable material". At the end of Cycle III, the provided dictionary would be useable and the pupils should therefore learn the new words. The distribution of performances should therefore correspond to "perfect" material. At the end of Cycle III, the proposed dictionary should be "unsuitable" for the known words.

Thus we hypothesized that identical material is unsuitable for subjects who do not know how to use it as well as for subjects who know how to use it but who already know the meaning of the words that have to be defined. We also hypothesized that the paper version, with which the pupils were more familiar, should also be more useable since there is no transfer.

We hypothesized that a dictionary would be useful when it makes it possible to learn the definition of an unknown word and useable when it makes it possible to find the sought-for definition.

Method

The 49 pupils who took part in the experiment came from three different classes at three different schools in the Tarn et Garonne department in the south-west of France. Of the pupils, 39 were in the third year of Cycle III, 6 in the second year and 4 in the first year (we have initially planned to ask 25 pupils of the first year to participate but the task was far too difficult for them). There were 32 girls and 17 boys. The experiment was conducted in June, at the end of the school year.

The subjects completed the task individually. The pupils were given a 6-page notebook with one word to be defined on each page. The words were: Epitaph, Bruise, Didascalie, Snail, Bottle, Staircase. In French, these words consist of either three or four syllables and occur at the beginning of the alphabet. Three of them were known to the pupils and three of them were not (this fact was checked in our experiment). The word presentation order was rotated so that, overall, each word appeared with the same frequency on each page of the notebook (i.e. 5 to 6 times).

The following instructions were given: “Hello, I'd like you to play the dictionary game. I'm going to give you a list of words. You know some of them and some you don't. You must try to write a definition for each word. So, two things are possible. You might think you need a dictionary so that you can look for the definition. But, watch out. I'm only going to give you one and a half minutes to find the definition. Then I'll ask you to tell me the definition. Or you might think that you don't need the dictionary and we'll go on to the next word”. Below the initial definition, the pupils were asked whether they were certain, not very certain or totally uncertain about the definition of each word.

Half of the pupils were asked to choose between the electronic and paper versions of the dictionary. The version was imposed for the other half (half of the pupils were given the electronic version and the other half the paper version). The pupils were distributed to the experimental groups on the basis of alphabetical name order. In both cases, the dictionary was closed after 1 minute 30 seconds or when the definition had been found thus making it impossible for the pupils to recopy the definitions.

Results

The pupils in the 1st year of Cycle III did not succeed in using the provided dictionary within the time allowed. When they were allowed to take their time, they needed between 8 and 18 minutes to find the definitions. We therefore decided not to continue after the first 4 pupils since these had been disconcerted by this impossible task. It should be noted that one pupil who took too long to find the first word (Bottle) decided not to use the dictionary for the remaining five words. He took 11 minutes to write down the six definitions.

As we hypothesized, the tool appears to be unsuitable since there is something to be learnt yet it is impossible to use the material. To learn a new word from a dictionary, it is necessary to have learnt to use the dictionary.

For the 45 pupils in the 2nd and 3rd years of Cycle III who looked up 6 words (i.e. 270 definitions), we observed that the dictionary was almost a "perfect" tool for the unknown words (see Table 4). It was 80% useful and useable. To use Bernard's terminology (1999), there was a quasi-conjunction relation of .80 between the learning of the new words and the use of the dictionary. In contrast, in the case of the known words, even though the dictionary is useable (and used) it is useless. The pupils appeared to overuse the dictionary whatever the version they had at their disposal.

Insert table 4 about here

Of the pupils who were given the choice, 19 preferred to use the electronic dictionary and 4 the paper dictionary. If we add together the behaviour of the pupils who were given the choice and that of the pupils who had no choice then we obtain frequency distribution presented in Table 5.

Insert table 5 about here

In contradiction of our hypothesis, there seemed to be little difference between the use of the paper and electronic dictionaries. However, we may note that in cases where the dictionary was, a priori, useless the pupils tended to use it more often when in possession of a paper rather than an electronic version. Our observations also seem to indicate that, overall, the average time taken by pupils to find a definition in the electronic dictionary was less than that required for the paper dictionary.

General discussion

In this article we have discussed various possible relations between the use of material and learning. We have suggested describing these relations in a logical way. This logical framework makes it possible to formulate direct hypotheses concerning the relation between the use of learning materials and learning itself. This logical framework also permits the joint interpretation of the results obtained in experiments in which binary variables can be used to measure the use of the material, on the one hand, and learning on the other. We have illustrated these points on the basis of an experiment. This framework lacks a statistical method making it possible to decide which column of the truth table corresponds to the obtained results, what is the level of significance of the results and how non-binary variables should be treated. We are currently working on the development of just such a method.

CLT is a theory which, amongst other things, makes it possible to evaluate and improve learning material. Within this theory, the reversal effect shows that the improvement of learning material tends to make processing more difficult as the expertise of the learners increases. Thus it increasingly appears that CLT is a theory of relevance (Sperber & Wilson, 1995), that is to say a theory of the relation between the learning material, learning goal and learner. This theory should be formulated as follows: The learner processes the material in a certain way because she or he believes that the designer has tried to design relevant materials to make her or him achieve the learning goal. Our framework makes it possible to formulate hypotheses concerning the relation between the learning material, learning goal and learner. It therefore allows us to consider CLT as a refutable theory of relevance.

References

Anderson, J. R. (1990). The adaptive character of thought. Hillsdale, NJ: Lawrence Erlbaum.

Anzaï, Y., & Simon, H. A. (1979). The theory of learning by doing. Psychological Review, 86, 124-140.

Bernard, J. M. (1999). Implicative analysis for multivariate binary data using an imprecise Dirichlet model. 1st International Symposium on Imprecise Probabilities and Their Applications, Ghent, Belgium, 29 June – 2 July.

Berry, D. C. (1997). How implicit is implicit learning? Oxford: Oxford University Press.

Cunningham, A. E. (1990). Explicit versus implicit instruction in phonemic awareness. Journal of Experimental Child Psychology, 50, 429-444.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. Human Factors, 40, 1-17.

Mousavi, S., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. Journal of Educational Psychology, 87, 319-334.

Myles-Worsley, M., Johnston, W. A., & Simons, M. A. (1988). The influence of expertise on X-Ray image processing. Journal of Experimental Psychology : Learning, Memory and Cognition, 14, 553-557.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics : a cognitive-load approach. Journal of Educational Psychology, 84, 429-434.

Perfetti, C. A., Beck, I., Bell, L. C., & Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal study on first-grade children. Merill-Palmer Quaterly, 33, 283-319.

Pierce, K.A., Duncan, M. K., Gholsn, B., Ray, G. E., & Kambi, A. G. (1993). Cognitive load, schema acquisition, and procedural adaptation in nonisomorphic analogical transfer. Journal of Educational Psychology, 85, 66-74.

Sander, E., & Richard, J. F. (1997). Analogical transfert as guided by an abstrction process: The case of learning by doing in text editing. Journal of Experimental Psychology: Learning, Memory and Cognition, 23, 1459-1483.

Sperber, D., & Wilson, D. (1995). Relevance. Communication and cognition. Second edition. Oxford: Blackwell.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science, 12, 257-285.

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. Journal of Educational Psychology, 81, 457-466.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. Cognition and Instruction, 12, 185-233.

Sweller, J., van Merrienboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. Educational Psychology Review, 10, 251-296.

Tricot, A. & Tricot, M. (2000). Un cadre formel pour interpréter les liens entre utilisabilité et utilité des systèmes d'information (et généralisation à l'évaluation d'objets finalisés). Colloque Ergo-IHM 2000, Biarritz, 3-6 octobre.

Tuovinen, J., & Sweller, J. (1999). A comparison of cognitive load associated with discovery learning and worked examples. Journal of Educational Psychology, 91, 334-341.

List of tables

Table 1. Truth table
Table 2. Contingency table
Table 3. Truth table with real values replaced by probabilities
Table 4. Relations between learning and use as a function of whether the words are known or unknown
Table 5. Relations between learning and use as a function of whether the words are known or unknown with the electronic or paper dictionary

Table 1
Truth table

AK_1UM_1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1
AK_0UM_1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	1
AK_1UM_0	1	0	0	1	1	0	0	1	1	0	0	1	1	0	1
AK_0UM_0	0	1	0	1	0	1	0	1	0	1	0	1	0	1	1
Interpretation	$\vee$	=>	UM_1	<=	AK_1	$\Leftrightarrow$	$\wedge$	/	w	AK_0	$AK_0 \Rightarrow UM_1$	UM_0	$AK_1 \Rightarrow UM_0$	$\downarrow$	T

Table 2
Contingency table

	UM success (rep. as UM_1)	UM failure (rep. as UM_0)
AK success (rep. as AK_1)	f AK_1UM_1	f AK_0UM_1
AK failure (rep. as AK_0)	f AK_1UM_0	f AK_0UM_0

Table 3
Truth table with real values replaced by probabilities

AK_1UM_1	.33	.33	.5	.33	.5	.5	1	0	0	0	0	0	0	0	.25
AK_0UM_1	.33	.33	.5	0	0	0	0	.33	.5	.5	1	0	0	0	.25
AK_1UM_0	.33	0	0	.33	.5	0	0	.33	.5	0	0	.5	1	0	.25
AK_0UM_0	0	.33	0	.33	0	.5	0	.33	0	.5	0	.5	0	1	.25
Interpretation	$\vee$	=>	UM_1	<=	AK_1	$\Leftrightarrow$	$\wedge$	/	w	AK_0	$AK_0 \Rightarrow UM_1$	UM_0	$AK_1 \Rightarrow UM_0$	$\downarrow$	T

Table 4
Relations between learning and use as a function of whether the words are known or unknown

	Known words		Unknown words	
	Used	Not used	Used	Not used
Learnt	3 (f =.02)	6 (f =.04)	108 (f=.80)	0 (f =.00)
Not learnt	90 (f =.67)	36 (f =.27)	22 (f =.16)	5 (f =.04)

Table 5

Relations between learning and use as a function of whether the words are known or unknown with the electronic or paper dictionary

	Known words		Unknown words	
	Used	Not used	Used	Not used
	Electronic dictionary			
Learnt	.02	.06	.81	.00
Not learnt	.58	.33	.14	.05
	Paper dictionary			
Learnt	.02	.00	.78	.00
Not learnt	.86	.12	.22	.00