English translation of: Christiansen & Olsen (2006): Analyse og design af didaktiske situationer. *MONA,* 3. 7-23

Analysis and design of didactic situations: a pharmaceutical example

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A 29-year-old man took his allergy medication twice daily for a year. One day, he drank two glasses of grapefruit juice before he took his medicine. He died shortly after. The autopsy showed increased levels of the drug in his body. On the basis of this case, a teaching session on recognition and conversion of pharmaceutical drugs in the human body is described. The lesson is analysed on the basis of the Theory of Didactic Situations; a theory that was originally developed within the didactics of mathematics didactics. The authors argue that this theory can be used when analysing and designing teaching situations in many subjects other than mathematics (e.g. chemistry and pharmaceutical subjects) at all educational levels.

Introduction

Characteristic of teaching at university and upper-secondary-school level is that this kind of teaching aims at students gaining specific knowledge. At upper-secondary-school level this knowledge (learning objectives and core material) is specified in the curriculum for each subject, and it is up to the individual teacher to decide how to plan his or her teaching over a longer period. Technical and natural science subjects at university level are often taught by a group of teachers, and the knowledge aimed at is typically specified in course plans prepared by the course manager(s) (and approved by the study board). Numerous ‘rank-and-file’ teachers in technical and natural science subjects are responsible for smaller parts of the course, however an overall specific academic agenda is set for the teaching as a whole.

We may ask “How can we plan teaching that is both challenging and motivating for the students, and at the same time ensure that they actually learn what they are supposed to learn?” Of course, there are many answers to this question, as well as several theories about learning and teaching that can shed light on this. In this article we focus on one of these theories, the theory of didactic situations (TDS). As an example, we outline a lesson about recognition and conversion of pharmaceutical drugs in the human body, and on the basis of this lesson, we describe several fundamental principles from TDS that we believe can be useful if we are to achieve the goal of offering challenging and motivating teaching when analysing and planning teaching. The theory of didactic situations was developed by Guy Brousseau, a researcher within the field of mathematics didactics

(Brousseau, 1997, also see Winsløw 2006, 2006b). Brousseau based his theory on the study of mathematics teaching (especially at primary and secondary level), however we will illustrate that his theory can also be applied in many other technical and natural science subjects (e.g. chemistry and pharmaceutical subjects), and that his theory is also useful when dealing with university teaching.

We believe that our description and analysis of a specific lesson offers a concrete example of the theory's applicability when analysing teaching situations. Brousseau's theory is not only applicable when *analysing* teaching situations (our focus here), but can also be used *to design* teaching situations. For example, the teaching material and teaching plans used today are soon to be updated, and it is in this context that TDS can be used. Thus analysis and design are usually two sides of the same coin, and we hope that readers will also see the potential of the theory when designing teaching, even though this article focuses on analysing teaching.

Description of the lesson

The following example is based on a teaching session on the *recognition and conversion of pharmaceutical substances in the liver*.

In principle, the lesson includes an introduction to the subject and the students are asked to work on an overall assignment. In the process, the students are given two shorter assignments that together deal with the central elements of the subject (criteria for recognition and conversion of pharmaceutical drugs). The teaching as described here was tested in connection with the course *Introduction to University Teaching*, carried out at the Department of Science Education and the Faculty of Pharmaceutical Sciences in November 2005. As a central part of this course, participants (typically assistant professors and PhD students) plan and teach a lesson lasting approximately 25 minutes. The course participants had very different academic backgrounds, and therefore the level was set to match the highest level for chemistry/biology at upper secondary school or the first year of university. In connection with the course *Structural Chemistry*, a fourth-year subject in the MSc programme in pharmaceutical sciences, the same subject was taught as described here and on the basis of the same principles (however at a higher academic level).

The knowledge aimed at

Upon ingestion of a pharmaceutical drug, the drug is absorbed into the body and delivered to the part of the body where it has an effect. However, it is important that the drug can be broken down in the body again, after it has done its job. This typically happens through a number of various reactions that convert the drug into substances that the body can more easily break down. Drugs can be converted via a number of enzymes that are found in the liver and other organs. In order for a substance to be converted by liver enzymes, it is crucial that first the drug is *recognised* by the liver enzymes (in the same way that a key fits a lock). However, it is not enough that the drug is recognised, the enzymes must also be able to convert the drug. An important characteristic of enzymes is that in addition to recognising a drug, they also play an important role in the conversion of the drug. This distinguishes enzymes from the other proteins in our body that merely recognise substances.

The knowledge aimed at and the objective of the lesson is for the students to understand the basic mechanisms of enzyme recognition and conversion of pharmaceutical drugs in the human body, and for them to be able to account for phenomena related to lack of conversion of a drug.

The lesson

The lesson begins with a presentation of two cases (described in text box 1). The objective of the lesson is for the students to be able to explain why a 9-year-old boy who had taken antidepressant medicine and the 29-year-old allergy patient died, on the basis of their knowledge about recognition and conversion of pharmaceutical drugs in the liver.

Text box 1A
A 29-year-old man from Australia on allergy medication drank a couple of glasses of grapefruit juice a week. He took his medication twice daily for a year. One day, he drank two glasses of grapefruit juice immediately after having taken his medication. After which he mowed the lawn. Soon after he felt poorly, collapsed and died. The autopsy showed elevated levels of the drug in the man. (Spence, 1997)

Text box 1B
A nine-year-old American boy with Tourette's syndrome (tics, etc.), DAMP and other difficulties was given antidepressant medication over a period of 10 months. During this period the boy's situation deteriorated, he suffered from epileptic fits and heart attacks, and finally he died. The autopsy showed elevated levels of the drug in the boy. (Sallee et al., 2000)

Obviously, the students cannot immediately explain why the two patients died (this is what they are to learn in the lesson), however the two cases are so spectacular that their interest is awakened. This is not least because the situations described are perceived as being realistic. Many students take medication on a regular basis themselves, or they know someone who does, so they find it easy to relate the two cases to their own world.

After presenting the two cases, the teacher begins to present a sub-assignment. It is important that the students understand the methods of representation to be used in the assignment, and the teacher describes these.

Figure 1 illustrates the basic principles for the conversion of drugs and introduces the representation method to be used in the lesson. In figure 1a, a molecule (a drug) is illustrated as a surface and a ‘ball-and-stick’ model (each ball and stick represents an atom and a bond between two atoms, respectively). What is important here is the *surface* of the molecule and the electrical charge in the different areas of the molecule. Therefore, in the lesson, figure 1a is simplified as seen in figure 1b. The colour scale (light-grey, black, dark-grey) represents neutral, positive and negative areas of the molecule. Figure 1d describes what happens when the drug is converted. Following conversion of the drug, there are two new charged areas to the right of the drug. Substances where larger areas are charged (more polar substances) are more easily broken down by the kidneys.

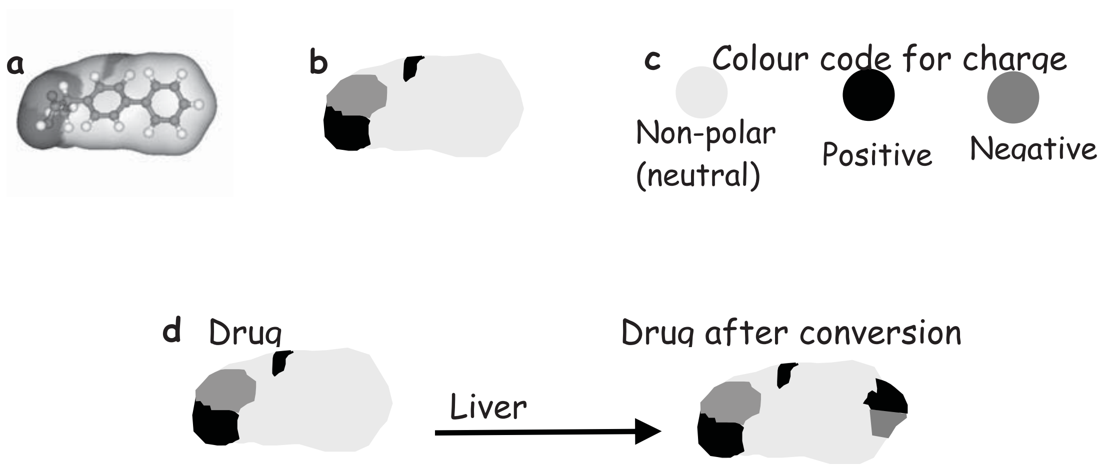

Figure 1. *Representations of the drug molecule and the principles for conversion. (a) The molecule is seen as a ‘ball-and-stick’ model, encapsulated by the surface of the molecule. (b) Schematic drawing of the surface of the molecule. (c) Colour code for charge of molecule surface. (d) The liver enzyme converts the drug into another substance that has increased surface charge (is more polar) and therefore is easier to break down in the body.*

The teacher explains that in order for a drug to be broken down in the liver, the drug needs to be recognised by the liver enzymes. It is crucial to the recognition process that the drug’s shape fits into the enzyme and that the drug and enzyme’s electrical charges match one another.

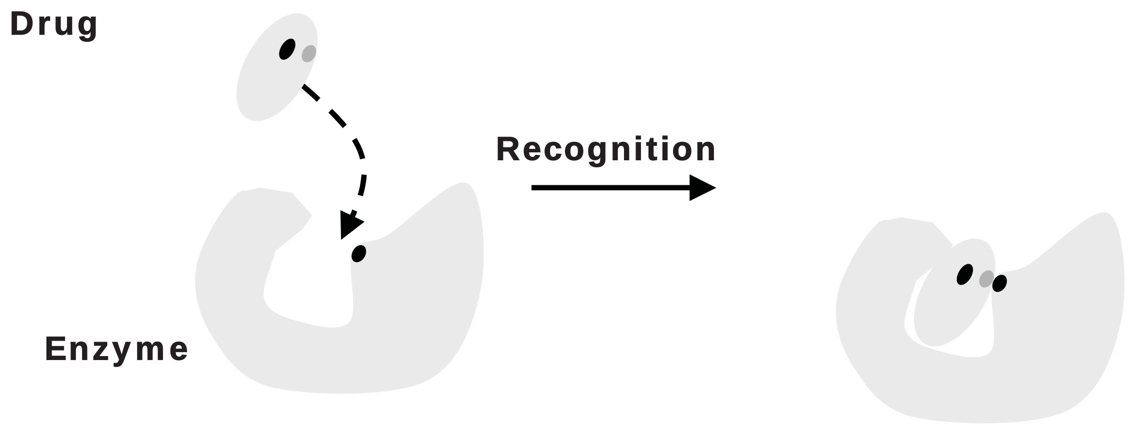

Figure 2. *A liver enzyme recognises a drug on the basis of shape and charge. Here the enzyme surface is depicted in the same manner as in figure 1.*

As is seen in figure 2, here the drug is almost a perfect match with the liver enzyme. There is recognition because a significant neutral area of the drug matches a corresponding neutral area in the liver enzyme, and the charged areas of the drug match areas with the opposite charge in the enzyme. After this brief introduction, the students are instructed to work on assignment 1a (described in figure 3). The students are given a piece of paper with the assignment on it as well as a pair of scissors that they can use when working on the assignment. The instructions and the 'rules' the students are to base their work on can be seen in the figure text.

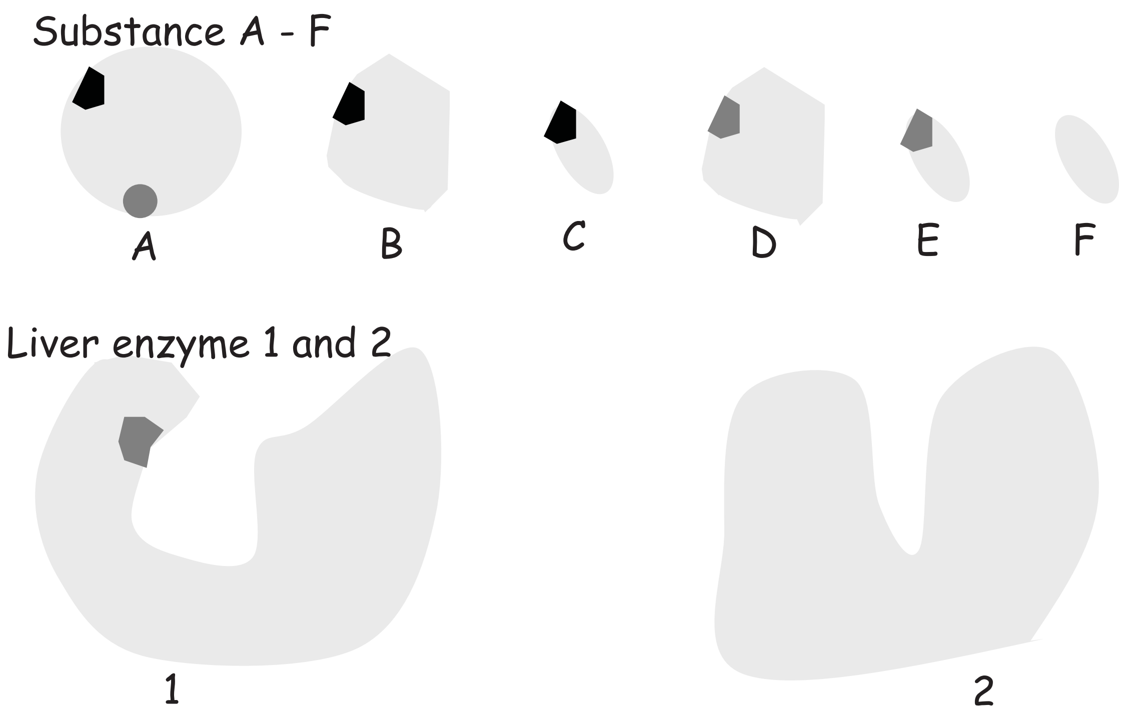

Figure 3. *Assignment 1a On the basis of the following rules, determine which of the substances (A-F) are recognised by the liver enzymes (1-2). Light-grey prefers light-grey to nothing. Dark-grey and black attract one another. Monochrome black and monochrome dark-grey repel one another. Spatial overlap between the substance and the enzyme is not allowed. Dark-grey and black are neither attracted nor repelled by light-grey.*

After working together in small buzz groups for a few minutes, the students present their results in a plenary session. This leads to the following points: First of all, some drugs have an extremely good match, both with regard to shape and ‘colour’ (B and C fit enzyme 1). Furthermore, some drugs fit both liver enzymes (*C*, *E*, *F*), however they prefer one liver enzyme compared to the other (*C* fits best into 1, *E* fits well into 2, *F* fits best into 2).

This covers how liver enzymes *recognise* drugs, however the enzymes must also be able to *convert* these drugs. How this is done is illustrated in figure 4. In the conversion process the enzyme negatively charges a neutral (light-grey) area of the substance. That is, there is *one more requirement* for conversion to take place after recognition.

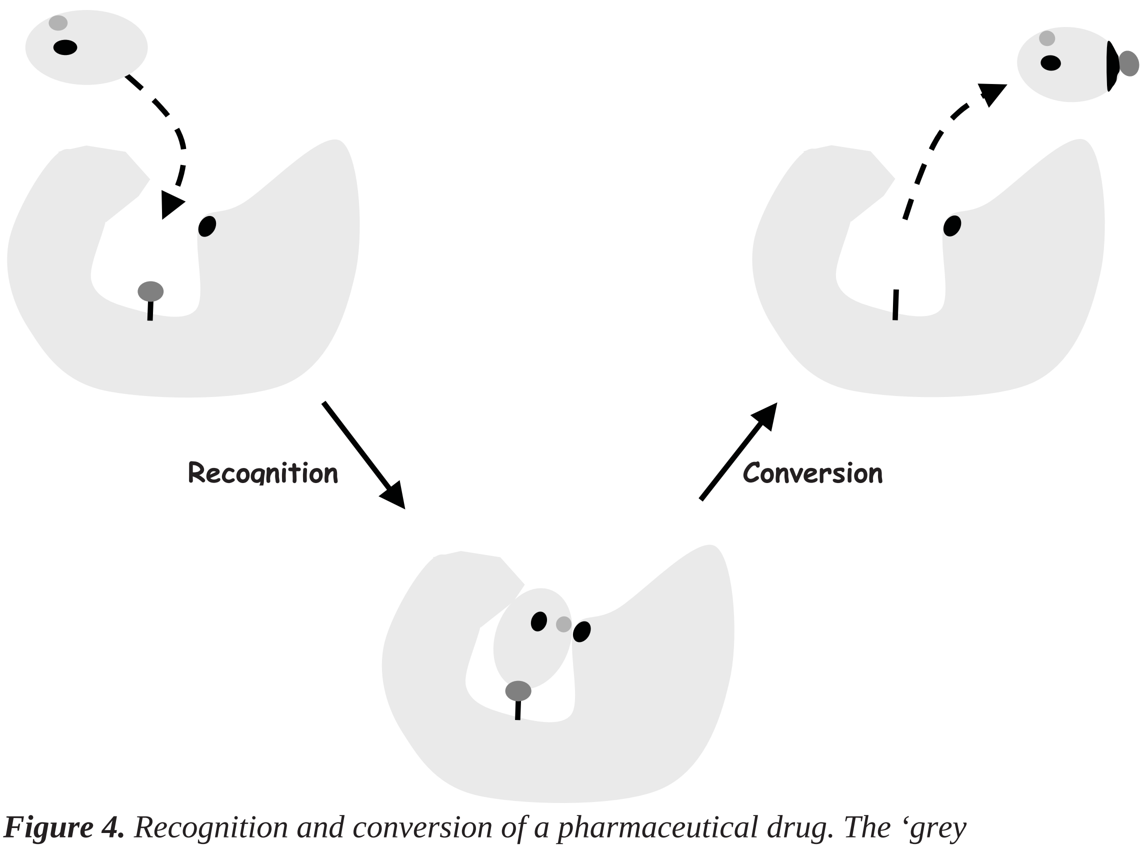

Figure 4. *Recognition and conversion of a pharmaceutical drug. The ‘grey ball on the stick’ that the enzyme adds to the drug is an oxygen atom.*

Because it is negatively charged, this atom contributes to increasing the drug's polarity.

After having explained this to the students, assignment 1b is presented. Here the students are to determine which of the drugs the liver enzymes will recognise and whether the enzymes can convert the drug (see figure 5).

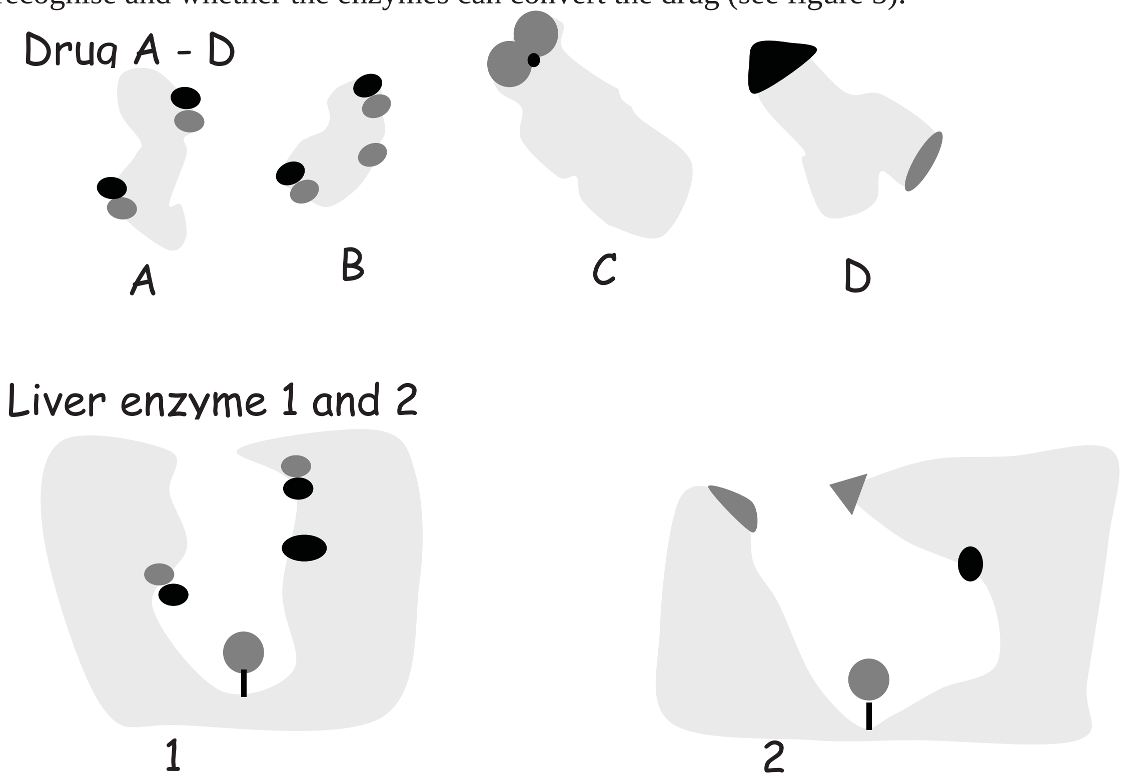

Figure 5. *Assignment 1b: Which liver enzymes recognise and convert the drugs? Rules for liver enzyme recognition and conversion of a drug: Rules of recognition from assignment 1 (see figure 3). Conversion requires that the 'grey ball on the stick' (the oxygen atom in the liver enzyme) is attached to the light-grey area of the drug.*

The students work with this assignment in the same way as with assignment 1a, and the assignment is also rounded off in a plenary session. However this time, the academic points to be noted are: Drug *A* is recognised *and* converted by 1; *B* is recognised but not converted; *C* is not recognised by 1 or 2; *D* is recognised *and* converted by 2. Here the academic insight is that while some drugs may be both recognised and converted, some drugs are recognised, but not converted.

The students have now learnt about some of the basic principles for liver enzyme recognition and conversion of drugs through their work with the assignments and the ensuing discussion of their results. Now the teacher reverts to the two cases that opened the lesson. Figure 6 shows a depiction of the substances from the cases: allergy medication, grapefruit juice and antidepressant medication. The students are now asked to think about why the 29-year-old Australian asthma patient and the 9-year-old American boy died.

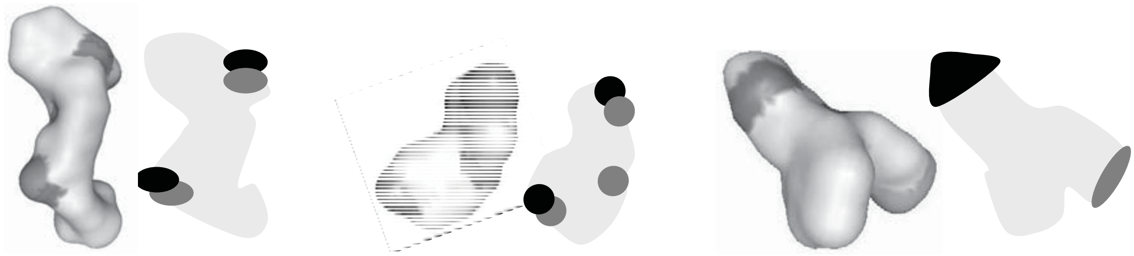

Figure 6. *Assignment 1: Why did the 29-year-old Australian man and the 9-year-old American boy die? Note the similarity between the substances used in assignment 1b (figure 5).*

One of the ingredients in the grapefruit juice blocks the liver enzyme that converts the allergy medication to another substance that is broken down more easily. This is why the allergy medication that the 29-year-old man is taking is accumulated in his body. The same inhibition of the conversion process may have been to blame for the accumulation of the antidepressant medication in the 9-year-old boy's body. However, this is not the case. The boy has a gene defect which entails that he lacks this enzyme completely and therefore there is no conversion nor breakdown of the substance (approx. 10% of all Caucasians have this gene defect). One way of avoiding these problematic situations is to design pharmaceutical drugs that are converted by more than one liver enzyme, so that another enzyme can take over the conversion process and thus ensure break down of the drug. The molecules *C*, *E*, and *F* in assignment 1a could potentially be such a substance (provided they can be broken down!).

Analysis of the lesson in the basis of TDS

In the following, we will first introduce the learning and epistemological foundation for the theory of didactic situations (TDS) and then analyse the lesson described in the above on the basis of the descriptions of the phases in the so-called 'didactic games' laid down in the TDS framework.

The epistemological hypothesis, learning as adaptation and didactic environments

The central concepts, methods and principles of a subject were developed in relation to certain types of situations and problems. The lesson described here mainly concerns the connection between recognition and conversion of pharmaceutical drugs in the human body. In many textbooks this is described in a manner that is fairly abstract, and it is a concept that students often find difficult to grasp.

The abstract approach in textbooks to the knowledge to be learned by the students is of course the result of a scientific process; originally the relevant knowledge constructed in relation to a specific situation or problem. These ‘original situations’ or problems are often not included in textbooks. The knowledge that was originally linked to a specific situation has been disjointed from the situation and generalised in order to describe not just the original situation, but a flurry of situations. We refer to “recognition and conversion of pharmaceutical drugs” as an objective knowledge area, without at the same time referring to specific situations in which the methods can be used. This generalisation process and ‘decontextualisation’ of knowledge is of course an important product of the scientific process, however it also entails a dilemma with regard to the teaching process. This is because human beings learn by relating to concrete situations. If knowledge is established historically (e.g. through the scientific process) and evolves on the basis of specific problematic situations, it seems obvious to say that all established knowledge is linked to a specific type of situation. One could also say that this knowledge can be (re)created by individuals in a similar situation and under similar circumstances. On the basis of this hypothesis, knowledge is thus the ‘answer’ to questions governed by a specific situation. This hypothesis is called “the epistemological hypothesis in science education” (Winsløw, 2006, section 1.4).

The perception of knowledge as the ‘answer to a question’ indicates a central problem in the teaching process. Of course we want to teach the students the *answers* (the knowledge aimed at), however answers rarely make sense without previous knowledge or understanding of the questions to which the answers are given. That is, it is necessary to ‘recontextualise’ the subject’s ‘decontextualised’ elements in order for them to make sense to the students. In the lesson described here, the three assignments are examples of such ‘recontextualisation’ of the general principles for enzyme recognition and conversion of substances.

Both the researcher and the student acquire knowledge by working with specific situations (typically together with others). If, through his or her learning, the student is to ‘rediscover’ the knowledge that the researcher has gained, situations where this (re)discovery can happen must be established. Obviously the history of science offers many such situations that can serve as the basis for the teacher’s planning of teaching situations (the journal *Science and Education* offers many good examples of this). However, it is just as clear that the students’ backgrounds (historical, cultural, academic, social, and possibly also cognitive) are usually rather different from that of the researcher, and therefore the history of science is seldom the best place to look for inspiration when designing a teaching situation. This points to the central issue that the ‘recontextualised’ situation must be relevant for student and his or her knowledge. If this is not the case, no learning can be expected. The importance of relevance in terms of personal experience is evident if we think of learning as ‘adapting to an environment’.

It is important that such ‘personification’ takes place and that the students can experience the teaching as both meaningful and relevant. In this lesson, the description of the two individuals who died of an overdose (assignment 1) is an important element in this personification. A connection to the student’s own life is established, spurring them to seek the solution to the assignment. Through their work with the two sub-assignments, the students find the solution to the main assignment (at least the part about the allergy patient). Pharmaceutical science has a wealth of such situations where a link can be established to the students’ own world or to their perception of what they will be dealing with professionally in the future, and this should of course be exploited in the teaching situation.

The need for relevance based on personal experience and the epistemological hypothesis reflects several standard pedagogical insights; insights that today are uncontroversial for most. More specifically, they reflect a basic inductively oriented constructivist approach to learning. Jean Piaget, who is often referred to as the father of constructivism, described learning as a personal construction process in interaction with an environment (see Winsløw, 2006, chapter 4), and Piaget’s fundamental metaphor for learning as ‘adaptation to an environment’ is also a important starting point for the theory of didactic situations (see. Winsløw, 2006b). Of course adaptation can only take place where the circumstances allow adaptation; this is why the material must be personalised. In addition to ‘recontextualisation’ of abstract knowledge, the materials used must also be ‘personalised’ by including the students’ own situation as an element in the teaching session.

This double requirement for personalisation and recontextualisation of abstract knowledge means that, as mentioned earlier, scientific situations in history on which the abstract knowledge is based seldom constitute good teaching situations. Instead, the teacher can create ‘artificial environments’ with a view to the student acquiring specific knowledge. Such ‘designed environments’, that are organised in such a way that the students acquire specific academic knowledge, are called *didactic environments* in TDS, and the interaction between the students and the didactic environment is called *the didactic game*. Let us revert to the didactic games in the lesson. Central to the design of didactic environments is that the students find the game challenging and that it motivates them to learn. Furthermore, when working with the situations, they are pointed in the direction of finding the answers to questions raised in the teaching subject. In our view, the three assignments described in the lesson constitute good examples of such didactic environments that together lead to students learning the knowledge aimed at (see Winsløw, 2006b, for a more detailed description of the concept ‘didactic environment’). The idea that didactic environments that have been specifically designed to allow the students to learn specific knowledge is a central expansion of Piaget’s description of learning in ‘natural environments’. Brousseau’s ‘environments’ (milieu) also differ from Piaget’s in other areas, e.g. Brousseau (along with others) emphasises the social relations in the environments and the importance of these relations for learning. Brousseau and Piaget agree that individual knowledge is constructed in a specific situation; on the basis of this situation; and on the basis of the knowledge the individual already possesses. The analogy of learning as ‘adaptation to an environment’ that both Brousseau and Piaget use, demonstrates their shared constructivist point of departure.

The teacher thus has an important task in designing teaching situations in which the students “can live and in which the knowledge [aimed at] appears as the optimal and discoverable solution to the given problem” (Brousseau, 1997, p. 22). In the lesson described here, designing the assignments (1, 1a, 1b) was by far the most time-consuming task. When working on the assignments, it is crucial that, within the framework of the assignments (the environment), the students are given the opportunity to express themselves and to act independently or in cooperation with others, and that the assignments actually enable them to acquire the knowledge aimed at. It is when working in the environment that the knowledge that is needed to solve the assignment is ‘personalised’ and the knowledge aimed at is (re)discovered on the basis of the student’s own construction:

> The modern view of teaching [...] requires that the teacher can provoke the expected adaptation in his or her students by presenting them with a carefully selected series of ‘problems’. These problems must be selected in such a manner that the students can accept them and they are motivated to act, think and evolve. [...] The students know very well that the problem they are presented with was selected with a view to helping them acquire new knowledge. However the students also know that this knowledge is completely based in the inner logic of the situation, and that they can construct it without calling on didactic reasoning. Not only *can* they do this, they *must*, as it is not until the students have fully acquired this knowledge that they are able to use it in situations outside of the learning context and where there is no guidance. This called an *adidactic situation*. Any specific ‘piece of knowledge’ can be characterised by one or more adidactic situations that secure the meaning of this knowledge. (Brousseau, 1997, p.30, the authors’ own translation)

Phases of the didactic game

An important element of the theory of didactic situations is the description of the various phases of the didactic game. The didactic game refers to the interaction between the student and the didactic environment. Even though the phases that the concepts describe seem almost self evident, or maybe precisely because of this, the concepts are surprisingly useful in both the analysis and design process of teaching situations. This is not least because the conceptual framework is independent of the specific teaching methods used. Overall, the phases refer to the relationship between the agents and the knowledge aimed at, and the situations that this knowledge is an ‘answer’ to. Therefore the conceptual framework is very broad and can be used as a ‘first iteration’ when planning teaching or, as here, when analysing existing teaching. The five phases in the didactic game are shown below, table 1 describes the flow of the lesson in question on the basis of these five phases.

- **Devolution:** The teacher passes a ‘didactic environment’ to the students
- **Action:** The students work in the environment
- **Formulation:** The students express themselves and create hypotheses about the solution to the assignment, either independently or in groups.
- **Validation:** The students test their hypotheses together or with the teacher.
- **Institutionalisation:** The teacher relates the work being carried out in the environment to the general themes of the subject, typically through a dialogue with the students.

The list of bullets is not to be understood as that the phases must follow one another in this precise order. However the phases are related to one another in specific ways, and this is what makes the concepts so useful. The devolution phase leads up to the action and formulation phases, the validation phases combine and ‘set a value’ on the formulations and actions. The institutionalisation phases express the results of the students’ efforts in the environment in a ‘formal’ academic manner that can be linked to ‘shared’, (and therefore useful) knowledge to be used in other situations as well as in the teaching situation in question.

Table 1. *Outline of lesson focusing on the teaching phases.*

General introduction	**Specialised sub-session**	**Situation**
Devolution: Assignment 1		Didactic
	Devolution of assignment 1a: Rules of recognition	Didactic
	Action/formulation/validation	Adidactic
	Joint validation assignment 1a	?
	Institutionalisation assignment 1a:	Didactic

	Devolution of assignment 1b: Rules for recognition and conversion	Didactic
	Action/formulation/validation	Adidactic
	Joint validation of assignment 1b	?
	Institutionalisation of assignment 1b	Didactic
	Devolution: assignment 1	Didactic
	Formulation/validation assignment 1	Adidactic
Joint validation of assignment 1		?
Institutionalisation		Didactic

Table 1 describes the lesson consisting of a general introduction to the overall assignment (the two patients who died of an overdose), and an embedded sequence based on the two sub-assignments (recognition and conversion of pharmaceutical drugs). It is stated for each phase whether the situation is didactic or adidactic.

On the basis of the outlined lesson, we will analyse the various phases of the teaching process and identify overall aspects of interest.

Devolution:

Devolution is the teacher's surrender of a 'didactic environment' to the students. There are three devolutions in the lesson: The overall introduction to the lesson including description of the two patients who died of an overdose. Next, the introduction to assignment 1a that is about how liver enzymes recognise drugs, and finally an introduction to assignment 1b that is about the conversion of drugs. Devolution is typically a teacher-controlled activity in which the students are given instructions. It is important that in the course of the devolution phase, students understand the task to be undertaken correctly, and they must be given the opportunity to ask clarifying questions. Most often what is going to happen in the course of the lesson is clarified (more or less explicitly) in the devolution phase, and it is also here that the teacher's and students' roles are defined. In the lesson described here this is especially true of the preliminary devolution in which the overall course of the lesson is outlined: Here's a mysterious phenomenon! When you have dealt with two short assignments, you will be able to explain this.

It is also worth noting the relationship between the two shorter assignments (1a and 1b) and the final solution to the overall assignment. The didactic environments that the students work in are not independent of one another. More specifically, the formulation of assignment 1 is included in the environment for assignment 1a along with 'puzzle pieces', scissors and the rules for recognition of drugs. Together these elements make up the (objective) didactic environment. When working on assignment 1b, conclusions from the previous assignment (1a) are included as part of the environment, e.g. the same rules apply to recognition of substances in assignment 1b as in 1a. Furthermore the students have now seen that they can solve these 'puzzles' on the basis of the given rules. In this way the lesson can gradually increase in complexity as the students acquire more relevant knowledge.

Action, formulation and (adidactic) validation

In the lesson described here, as is often the case, the action and formulation phases are closely interconnected, not least in assignments 1a and 1b. The students work together in small groups; first they cut out the puzzle pieces, then they match them with the liver enzymes and discuss each piece on the basis of the overall rules that are specified in the assignment. While the students are trying out the pieces and independently expressing themselves on the subject, it is important that the teacher remains in the background. This can be very difficult for a teacher who most often wants to be involved in the discussion (and should be too), however the teacher should also clearly signal that he or she expects the students to work independently of the teacher. The teacher should only intervene in situations where the students cannot seem to get started on the assignment.

As the students progress with their work, they construct hypotheses about which pieces match which liver enzymes, which substances are recognised, which substances are converted, etc. These findings are discussed in the individual groups and the arguments for the hypotheses put forward are also discussed here, i.e. why the substances are recognised and converted. This is a validation situation, albeit a validation made by the students, without any interference from the teacher, a so-called adidactic validation. Often these adidactic validation situations give rise to new actions and formulations: "No, that one doesn't fit in here because then you would have two positive charges opposite one another. But what if we rotated it like this...?" It is not difficult as such to distinguish between the action, formulation and validation phases, however the shift between the phases is often very fast. The adidactic validations are, in our opinion, very important because the students are given the opportunity to substantiate their (own) hypotheses, and this process is central to their learning. As validation takes place on the basis of actions and formulations in the environment, it is important to allot sufficient time to the assignment to ensure that the students reach beyond the action and formulation phases.

Validation and institutionalisation

After the students have worked on the assignments in groups and reached a conclusion, their findings are presented in a plenary session. This is also a validation situation, however in contrast to the validation that took place in the groups, here the teacher plays a significant role. The teacher has the 'correct' answers and can therefore 'set a value on' and add to the students' arguments in a way that the students normally cannot. However, the thoughts have been thought by the students themselves, and most often the teacher's role in this situation is to coordinate and steer the discussion so that the groups that may not have reached the correct solution also learn from the other students' solutions. In the process, the students may comment on one another's answers, or the students may have found a particular part of the assignment challenging that was not anticipated in advance. Even though this validation is 'teacher controlled', it clearly reflects the students' own thoughts in the environment, and it can sometimes be difficult to say beforehand exactly how the rounding-off process will proceed (this explains the question marks in table 1). However, if the assignment is well-designed, it will often be possible for the teacher to reach exactly those points that the assignment aims at.

Whereas the design of the assignments and the students' approach to them aimed at 'recontextualisation' and 'personification' of the knowledge aimed at, the objective of validation is for 'collectivisation' of the knowledge the students gain through their work in the environment. However, this knowledge is still linked to the specific assignment the students have been working on. Therefore institutionalisation is needed, where, on the basis of the validation, the teacher describes how the specific situation related to the subject in general as well as the knowledge aimed at:

> the teacher's work is to some degree the opposite of the researcher's work; the teacher must *recontextualise* and *repersonalise* the knowledge [aimed at]. It must become the student's knowledge; i.e. a reasonably natural response to relatively specific conditions; conditions that determine whether the knowledge aimed at makes sense to the student. Any acquisition of knowledge is based on adaptation to a specific situation. [...] However the teacher must also create room for discovery of the culturally embedded and communicable knowledge that she wants to teach the students within the story that the students recreate. Subsequently, the students must *re-decontextualise* and *re-depersonalise* their knowledge in such a way that they can determine which parts of what they have learnt lie within the normal scope of the scientific and cultural community. (Brousseau, 1997, p.23, the authors' own translation)

In the final institutionalisation of the lesson described here, the teacher discusses with the students what the typical causes are for lack of conversion of a drug (that the relevant liver enzymes are 'taken' by other substances, as in the first example, or due to a gene defect, as seen in the second example). She also discusses with the students the research being carried out in developing pharmaceutical drugs that can be converted by several liver enzymes, and finally gives an example of how, what is represented here by a very simple puzzle, can be transferred to a 'real' enzyme that is significantly more complex to grasp. In this way emphasis is on the general mechanisms for recognition and conversion in play in the situations, and to a lesser degree on the specific representations (that the students probably will never encounter again).

In connection with assignment 1, it is worth noting that the students actually cannot explain why the boy with the gene defect died *solely* through their work in the environment. This indicates that there may be a difference in the way in which the theory of didactic situations is used in mathematics compared to the natural sciences. In mathematics there are no such ‘exceptions’ to the rules that apply in the didactic game. In the natural sciences there are very often exceptions to the rules that are used. In the lesson the students are led to the assumption that the liver enzyme is ‘taken’ by another substance. This is also the case in a typical situation, however it is not the case here. At this stage the students know the principle rules of recognition and conversion and understand the explanation immediately. The assignment could easily have been expanded to include another smaller assignment in which the students were asked to explain which of the rules applied in assignment 1 is problematic, considering that they now know that another substance has not ‘taken the place’. If we did this, we would undoubtedly see that the students could explain why the boy died themselves.

Use of TDS

The theory of didactic situations was, as mentioned, developed within the field of the didactics of mathematics and it has found widespread use in this field. Brousseau and his colleagues demonstrated great creativity in their development and examination of a vast range of didactic situations in mathematics teaching at (especially) primary and secondary level. Obviously these situations are closely linked to mathematics. In that sense there is no doubt that the theory of didactic situations is almost exclusively a didactic theory for mathematics.

However, the theory uses a conceptual framework that can be used in a more general sense, including an understanding of learning and a basic description of teaching situations that not only bear relevance to the didactics of mathematics, but that are also relevant in the didactics of other subjects, at least the didactics of the natural sciences and technical subjects. By this we especially mean the epistemological hypothesis, the two concepts didactic environment and didactic game, as well as the phases of the didactic game. These concepts are extremely useful in the analysis of teaching situations, as we have illustrated with the lesson on recognition and conversion of pharmaceutical drugs in the liver, and the conceptual framework is also useful when designing teaching.

It should be added that other central concepts from TDS that we have not included here due to lack of space, can also be used in other technical and natural science subjects, e.g. the concepts ‘didactic contract’ and ‘epistemological and didactic obstacles’. TDS has been used in other subjects than mathematics, e.g. physics (Thibergien, 2000) and physical education (Armade-Escot, 2005), however in our opinion it has greater potential than has been demonstrated in these few and far between studies. Finally, we would like to emphasise that the theory is not limited to design of teaching at primary and secondary level, but can be used with great success when dealing with teaching and learning at university level.

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