The car catalyst–students' misconceptions and how to challenge them

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ABSTRACT

The objective of this study was to find out what students already know about the car catalyst in order to design a module to pass on the scientific mental model to them. Therefore a questionnaire was given to students in 9th, 10th and 11th grade pupils. Questions referred to what happens inside a catalyst with the incoming gases. The misconception of a filter or a further combustion engine could be localized. According to the students the catalyst is equipped with netting which slices the molecules. According to the misconceptions received a topic was designed to overcome and cure these concepts and to clarify and give the pupils a valid picture of what happens inside the catalyst. In a post-test results are discussed.

KEYWORDS

Chemical education, car catalyst, students' misconceptions, mental models

RÉSUMÉ

L'objectif de cette étude était de savoir ce que les élèves savent déjà sur le catalyseur de voiture afin de créer un module pour passer sur le modèle scientifique mentale. Par conséquent, un questionnaire a été administré aux élèves de 9e, 10e et 11e grade. Les questions se réfèrent à ce qui se passe dans un catalyseur avec les gaz entrants. La représentation d'un filtre ou d'un moteur à combustion peuvent encore être localisée. Selon les étudiants, le catalyseur est équipé de filet qui tranche les molécules. Selon ces représentations un module a été conçue pour surmonter et guérir ces concepts et de clarifier et de donner aux *élèves une image valide de ce qui se passe à l'intérieur du catalyseur. Dans un post-test les résultats sont discutés.*

Mots-Clés

Enseignement de la chimie, catalyseur de voiture, représentations des élèves, modèles mentaux

Introduction

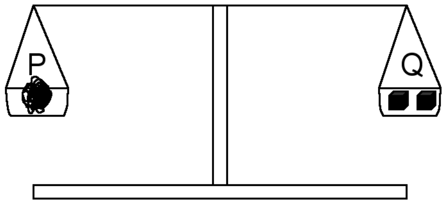
According to the national standards of education in Germany the aim of science education is to enable the individuals to participate actively in social communication, to create critical thinking, to obtain the problem-solving ability and to form an opinion on technical developments and scientific research. Nowadays it is well known and accepted that students bring their own ideas and notions that are well established in their ways of thinking into chemistry lessons. But these ideas are not consistent with the ideas accepted by the scientific community.

If we want to teach science we have to distinguish between *pre-concepts* and *school-made misconceptions* (Barke, Hazari & Sileshi, 2009). On the one hand there are concepts brought from home or from every-day life, we call them pre-concepts. Driver and Easly (1978) describe "the situation in which pupils have developed autonomous frameworks for conceptualizing their experience of the physical world" as *alternative frameworks*. In the literature one can find also "*alternative ideas*" or "*children's science*". On the other hand we know about school-made misconceptions which are caused by inappropriate teaching methods or by the complexity of a special topic, as for example chemical equilibrium (Bergquist & Heikkinen, 1990; Nakhleh, 1992; Tyson, Treagust & Bucat, 1999), redox reactions, acids and bases (Kolb, 1978), complex reactions, energy.

With regards to the pre-concepts we can take the example that students have special mental models about burning processes, they make good observations and find their own explanations, if students see a piece of wood combusting they say that "the wood is destroyed and something disappears unretrievably". As they observe the ash remaining and being lighter than the wood before, they have done their observation well but develop a "destruction concept". Also because of the every-day language students are led that way: Candles, spirits or gasoline completely "burn away", carbon "smolders", wood is "charred", stone is "weathered", metal "corrodes", iron "rusts" are some examples to point out.

In order to overcome the "destruction concept" (Barke, Hazari & Sileshi, 2009) the teacher may take a balance (see figure 1).

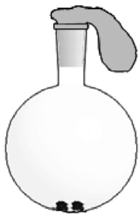
FIGURE 1



Balance with iron wool on pan P and some weights on pan Q

Iron wool is placed on pan P and weights are added to pan Q to balance the scales. The iron wool is removed and heated in the air. It forms a black substance which must be carefully collected and returned to pan P. Now the students can see, that the "black iron wool" weighs more than before. We have to explain that iron reacts with oxygen of the air to a new black substance called iron oxide. The amount of oxygen causes the higher mass.

FIGURE 2



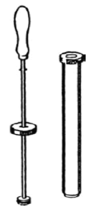
Round flask filled with charcoal and closed with an air balloon

For understanding that there are other observations when metals are burnt in a closed container, iron wool is taken in a test tube, closed by an air balloon and weighed on a balance. The test tube is heated and the black iron oxide is observed. After cooling down the mass of the test tube is measured again: the same mass is observed. By those experiments the law of conservation of mass is introduced and will lead to a conceptual change by the pupils.

Because iron burning is not known by the pupils one has also to prove the conservation of mass through burning charcoal, candles or spirits. In case of charcoal we can take a 2 liter round flask, an air and some pieces of charcoal and oxygen (see figure 2). Charcoal is taken in a round flask, the flask is filled with oxygen and closed with an air balloon and weighed. We heat the charcoal pieces from the outside until they glow, swirl the flask and observe light glowing by the burning pieces. Pupils can observe in the meanwhile that "charcoal is away". After the flask has cooled down we weigh the flask once again and observe the same mass as before. Now carbon dioxide can be proved with lime water. The mass before and after burning is the same, charcoal and oxygen weigh the same as the carbon dioxide afterwards. Later in other lessons the conservation of mass is explained by new grouping of C atoms and O_2 molecules to form CO_2 molecules. The number of C atoms and O atoms before and after the reaction does not change.

Another pre-concept is the concept of "gases as not substances" (Barke, Hazari & Sileshi, 2009). Regarding this question it is possible to show that gaseous butane changes to liquid butane under pressure.

Figure 3



Gas liquefying pump

Taking a gas liquefying pump (see figure 3) it can be filled with butane gas from cartridge of a butane burner through replacement of the air. When the piston is attached one presses strongly into the pressure-resistant test tube and lock it in place. A drop of liquid substance can be observed. When the lock is released again the gas extends and changes state from liquid to gaseous. In addition the density of air or butane can be demonstrated: 1,3 g/L for air, for butane 0,6 g/L in the liquid state and 2,6 g/L in the gaseous state is measured.

On the topic of gases, many incorrect ideas circulate in every-day language, too. Weerda (1981) collected some statements concerning the nature of gases: Cars emit "exhaust" to the air, colorless gases are "air" or similar to air, water evaporates and "forms air", gases are explosive, one finds "liquid gas" in lighters. "Cars emit exhaust to the air" is only one of the misconceptions referred to the gases as not substances. In order to address to these ideas, we need to discuss and finally to eliminate this misconception by taking the catalytic converter into consideration.

Catalytic converters are now included in almost every car sold in Europe. Millions of tons of hydrocarbons and carbon monoxide have been eliminated from the exhaust gases of cars, these toxic combustion by-products are converted to less-toxic substances (Koberstein, 1984; Buck, 1986). Almost all people have heard about the catalytic converter but the valid imagination is missing, the scientific mental model has not been passed on to students, respectively. Even if students are taught about the car catalyst at school the results of the questionnaire show that the teaching had been inappropriate or that the pre-concepts remained. According to Ausubel (1968) "the task of changing misconceptions will not be easy since misconceptions have often been incorporated securely into cognitive structure".

In this study we want to find out what students already know about the catalytic converter, what their misconceptions are and how the conceptual change takes place by teaching the catalytic converter in an appropriate way.

METHODOLOGY

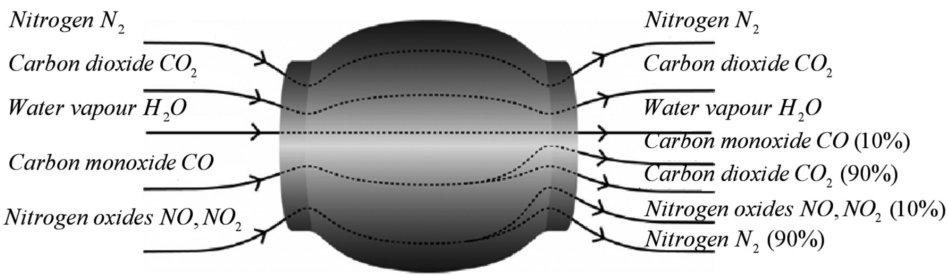
The sample

76 students from different grades participated in this study. The data are from responses of four different groups of students. Groups 1, 2 and 3 are course classes, group 1 is a techniques course (T) in grade 9, group 2 is a French course (F) in grade 9, respectively. Group 3 is a biology course (B) in grade 10 and group 4 is a composite grade 11 chemistry class. In total we had 76 students: 19 students in group 1, 20 students in group 2, 15 students in group 3 and 22 in group 4. The questionnaire was distributed at the end of a school year.

Design

The questionnaire from PISA 2006 was taken and distributed to students of 9th, 10th and 11th grade. The same questionnaire was used for the pre- and post-test. Only the questions about what is happening inside the catalytic converter (see figure 4) and what happens to atoms and molecules in detail are taken into consideration in this article. The other two questions refer to what engineers could improve to construct a better catalyst and to the general interest on technology. Our study consists of three parts: The pre-test, the teaching intervention and the post-test.

FIGURE 4



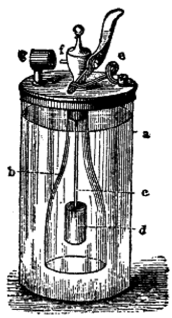
The catalyst in the questionnaire from PISA 2006

Teaching the catalytic converter – the teaching intervention

For the proposed topic, students of the 9th, 10th and 11th grade must have enough knowledge about the properties of air, the different gases and their percentage in air, the role of oxygen for the combustion and about the gaseous combustion products like water vapor and carbon dioxide. Therefore a three week topic was designed. For conducting a successful conceptual change, a real car converter was taken from the Mercedes Company and the students could look through the tiny pipes which are necessary to let the exhaust gases pass to the air outside the car. Now the question came up how the poisonous gases can be changed into harmless gases – and students are motivated to follow the lessons.

Taking the Doebereiner fire lighter (see figure 5) it can be demonstrated how hydrogen is reacting with small platinum crystals on the surface of quartz wool: hydrogen gas ignites and reacts with oxygen of the air. For explanation it has to be pointed out that H_2 molecules are separated into H atoms on the surface of platinum, and these H atoms react with O_2 molecules (which are also split into O atoms) to form H_2O molecules (Hülsmann, 1998). Platinum works as a catalyst he Doebereiner fire lighter produces hydrogen gas by the Doebereiner lighter reaction of zinc and sulfuric acid.

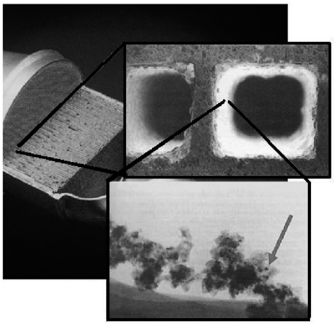
Figure 5



Doebereiner lighter

The electron microscopy image of the interior of a catalytic converter (Schüth, 2006) (see figure 6) was also shown to the students and they were asked to compare this image with the original catalytic converter in front of them. The magnification (2nd picture of figure 6) shows the interior surface of two pipes which can also be seen in the original catalytic converter. This surface consists of aluminum oxide and is called the wash – coat where tiny crystals of platinum metal are placed, i.e. the catalyst substance which cannot be seen with the unaided eye. But we can take hydrogen out of the steel container and flow against a piece of a car catalyst. In this way students realize the presence of platinum crystals as they glow and hydrogen ignites like it happens in the Doebereiner lighter.

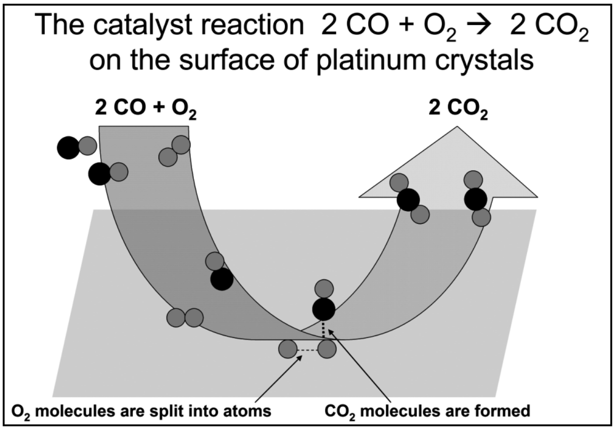
FIGURE 6



Electron microscopy image of the interior of a catalytic converter

But what exactly happens on the surface of platinum crystals? On their surface the same reaction takes place like in the inner catalytic converter of cars: carbon monoxide reacts to carbon dioxide because the O_2 molecules are split in the presence of platinum into O atoms, and CO molecules react to CO_2 molecules (Wedler, 1997; White & Campbell, 1980). NO molecules are separated into N atoms and O atoms, N atoms react to N_2 molecules (see figure 7).

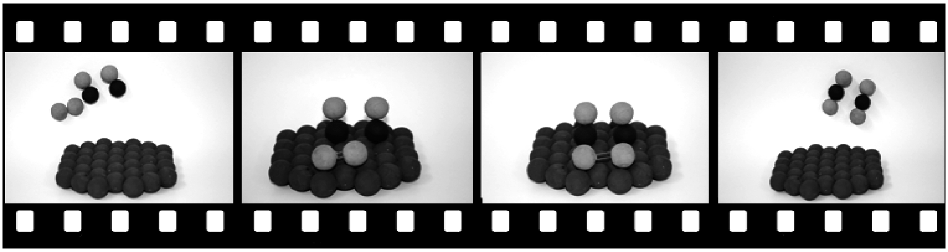
FIGURE 7



Structural model of the catalyst reaction

For visualization one can create model drawings which show the reaction on the surface of platinum crystals, students should build related molecular models (see figure 8) and simulate the reaction. By this activity students were able to construct their own mental model about the reaction mechanism of a heterogeneous catalytic process.

Figure 8



Molecular model of the catalyst reaction step by step

Furthermore the test of the efficiency of the catalyst was shown with a model experiment (Häusler, 1986; Dämmgen, 1988). Exhaust gas of a cold started car was taken in a syringe. In the exhaust gas carbon monoxide is shown by a special CO tester (Dräger company in Germany). The exhaust gas is pressed through a heated platinum model catalyst in a quartz glass tube, the new gas is collected by a second syringe on the other side. Afterwards the new gas is tested with the CO tester: no carbon monoxide could be shown. The evidence was provided that the catalytic converter converts harmful (here: carbon monoxide) into harmless gases (carbon dioxide). After the topic taught in all groups the pupils were asked to fill in the same questionnaire like before (post-test).

In the first item of the questionnaire pupils have to compare all the gases going into the catalytic converter to the ejected gases coming out of it. Students were asked to describe their mental model *in which way* a catalyst makes less harmful exhaust (see **Question 1:** Describe *in which way* a catalyst makes less harmful exhaust). In the second item students should explain at the microscopic level what happens with the atoms and molecules of the gases inside the catalytic converter (see **Question 2:** Inside the catalyst gases are changed. Explain what happens to the atoms **and** molecules).

Results

Pre-test

In the pre-test of question 1 the majority of the students (42%) believe that the catalyst is separating gases from each other as they mention that gases are split (see Table 1), believing that carbon monoxide consists of two kinds of gases: on the one hand carbon monoxide and on the other hand carbon dioxide. Answers like: "the catalyst segregates carbon monoxide from carbon dioxide", "the exhaust gases are crushed", "they are devided into two types of gases" are indications for this type of misconception. It reminds of the destruction concept when students suggest that magnesium "consists of magnesium and magnesium oxide" that after combustion only "MgO remains".

Concerning the correct answers in Table 1 33% of the students say that "gases are changed or converted" somehow in the interior of the catalyst, some of them also state the splitting and rearrangement. The misconception that the catalytic converter is a combustion engine comes along with the property to filter and store the gases. The students really believe that if the gases are not completely burnt, the catalytic converter "gives the gases *one more chance to get burnt*" (see False answers and Filter misconception in Table 1).

Here we can see the question and the categories of answers.

Question 1: Describe *in which way* a catalyst makes less harmful exhaust.

<u>Correct answers</u>: gases are converted/changed or split and re-arranged.

<u>Semi-correct answers</u>: gases are split.

<u>False answers</u>: gases are combusted, destroyed, gases are made harmless.

<u>Filter misconception</u>: gases are stored, are kept inside the catalyst.

<u>No answer</u> was given at all.

TABLE 1

Pre-test question 1

Categories	**Pre-test**
Correct answers	25 (33%)
Semi-correct answers	32 (42%)
False answers	7 (9%)
Filter misconception	11 (15%)
No answer	1 (1%)

The results are amazing with regards to the correct answers. Only 3 students know or have the correct image that a catalytic converter splits the molecules and atoms are rearranged to harmless gas molecules. But a lot of answers referred to the conversion or change of the gases and they are also counted as correct answers and we have an amount of 33% of correct answers. Within these correct answers there was also the idea of a "neutral" substance being responsible for the conversion of the gas molecules. In the post-test the platinum crystals as the catalyst material were mentioned to be responsible for the conversion and some students described the whole mechanism of the catalytic reaction they were taught about.

Concerning the second item of the questionnaire there were also built categories according to the answers of the students.

Question 2: Inside the catalyst gases are changed. Explain what happens to the atoms **and** molecules (see Table 2).

Correct answers: Molecules are split and atoms are rearranged in a different way.

Semi-correct answers: atoms and molecules are either split or rearranged

False answers: gases are filtered, stored.

False answers like reactions take place etc.

No answer was given at all.

TABLE 2

Pre-test question 2

Categories	Pre-test
Correct answers	21 (27%)
Semi-correct answers	24 (32%)
False answers	3 (4%)
False answers like reactions take place	20 (26%)
No answer	8 (11%)

Question 2 referred to what happens to the atoms and molecules inside the catalytic converter, students are asked to give answers with regards to the molecular level. All of them had been taught before about atoms and molecules but according to the given answers we can find still misconceptions. A lot of them are not in the position to differentiate between atoms and molecules and so they talk about "atoms and molecules of one substance that is split" (semi-correct answers in Table 2). The false answers handle with the misconception of a filter. Here, although the question referred to what happens with the atoms and molecules some students repeated the same answer like in question 1.

Post-test

After the teaching intervention that took place about three weeks the same questionnaire was filled in by the students so that we could investigate the effort they had done.

Question 1: Describe *in which way* a catalyst makes less harmful exhaust (see Table 3).

Correct answers: gases are converted/changed or split and re-arranged.

Semi-correct answers: gases are split.

False answers: gases are combusted, destroyed, are made harmless.

Filter misconception: gases are stored, are kept inside the catalyst.

No answer was given at all.

TABLE 3

Post-test question 1

Categories	Post-test
Correct answers	56 (74%)
Semi-correct answers	7 (9%)
False answers	6 (8%)
Filter misconception	7 (9%)
No answer	0

In total we have one third of correct answers before the teaching intervention. After teaching the topic of the catalytic converter we can see that more than 7 out of 10 students have adopted the right image about the catalytic converter (33% in the pre-test compared to 74% in the post-test). During the pre-test 42% of the students stated the splitting and segregation of the gases from each other, after the teaching there were just 9%.

The false answers were stated by students who believe in the filter-misconception, that gases are stored, destroyed or further burnt. We can see how difficult it is to overcome these misconceptions. Although students were able to look through the tiny pipes of the original catalytic converter and even being taught the catalytic mechanism with the molecular models over half of them still hold on their misconceptions of a filter (see answer "filter misconception": pre-test 11 students, post-test 7 students).

With regards to question 1 the mean score increased from 0.33 (sd = 0.47) on the pretest to 0.74 (sd = 0.44) on the posttest. The difference between the two means is statistically significant at the 0.01 level (t = 5.99, df = 75).

Question 2: Inside the catalyst gases are changed. Explain what happens to the atoms **and** molecules (see Table 4).

<u>Correct answers</u>: Molecules are split and atoms are rearranged in a different way.

<u>Semi-correct answers</u>: atoms and molecules are either split or rearranged

<u>False answers</u>: gases are filtered, stored.

<u>False answers like reactions take place etc</u>:

<u>No answer</u> was given at all:

TABLE 4

Post-test question 2

Categories	Post-test
Correct answers	42 (55%)
Semi-correct answers	11 (15%)
False answers	3 (4%)
False answers like reactions take place	13 (17%)
No answer	7 (9%)

Although students hold on their misconceptions we can also see an effort in the students' image about what happens inside the converter. In the pre-test there were one third with correct answers (see correct answers in Table 3). After the topic there was 55% with the right answers (see Table 4). The semi-correct answers show that the difference between pre- and post-test is about 6%. The false answers (reactions take place) show the results of the teaching with regards to the chemical reactions that take place inside the converter. They mention the reduction and oxidation but they do not state the way they happen. In comparison to question 1, a lot of students did not answer to question 2. Here, we can see one more time that students have big problems with the terminology of "chemical substances".

With regards to question 2 the mean score increased from 0.28 (sd = 0.45) on the pretest to 0.55 (sd = 0.50) on the posttest. The difference between the two means is statistically significant at the 0.01 level (t = 5.03, df = 75).

Discussion

This research project took place some weeks before summer vacation, at the end of the school year 2009/2010. According to the results of the pre- and post-test there is a growth of knowledge concerning the operation of a catalytic converter. Because of the complexity of the topic it is quite difficult to teach and therefore some of the students hold on their misconceptions they had before. Nevertheless, this first research project on catalysis investigated the student's misconceptions and should give an idea of one way to introduce it into school lessons as it is very important for our environment. On the other hand the understanding of the mechanism of a heterogeneous catalytic process is of great importance as most industrial products are produced with the help of a catalyst to save money, time and the environment/energy. In 2007 Gerhard Ertl was awarded the Nobel Prize in Chemistry for his studies of chemical processes on solid surfaces. There is planned a further research on first year chemistry students to investigate their suggestions on the catalytic converter.

After the topic the students gave their feedback on this topic. Most of them "were not enthusiastic about the catalytic converter before the teaching but now they are, they could not imagine that working with a real car catalyst makes that fun". Another feedback was that the student speaker said in the name of his class that "this topic is very interesting and of high level knowledge and that they are grateful for this introduction into such a complex topic". The feedbacks of the students in general were positive about this topic. Even if teachers do not like to teach they should give their students a chance to learn more about car catalysts and their function to protect our environment from toxic exhaust gases.

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