TESTING OF CHEMICAL LITERACY (CHEMISTRY IN CONTEXT IN THE DUTCH NATIONAL EXAMINATIONS)

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Abstract:
It is possible to write items assessing “chemical literacy skills”. Dutch National Chemistry Examinations assess not only the candidate’s knowledge and skills in chemistry, but also skills in using and dealing with information.
In our opinion we assess chemical literacy when we assess the ability of the candidates in:
. using and dealing with (written) information on a chemical problem;
. using chemical knowledge and skills for understanding information about an everyday problem.
This article shows examples of contexts used in chemistry examinations and examples of the format in which these contexts are presented.
Three examples of tasks from the National Chemistry Examinations in the Netherlands are presented. Items in these tasks are assessing literacy skills.

1. Chemistry examinations

1.1 Context

Citogroep (hereafter called CITO) is one of the world’s largest and most respected testing and measurement agencies. In addition to its tests and examinations, CITO offers advice and training on all aspects of assessment to government departments, local education authorities, training institutions, private companies, schools and teachers. Its services include consultancy, test development, training and logistical support.
CITO is commissioned by the Dutch government to develop national school examinations. Each year, up to 325 different examinations are produced. Results are analysed and the findings distributed to schools, teachers, students and other stakeholders.
Over the years, the level of difficulty of examinations and the differences in results between groups of students (for example, boys and girls) have been investigated and the findings reported. Research studies are published and the government is advised on the improvement of examinations.
CITO also contributes to in-service training courses for teachers where professional testing and assessment skills are developed.

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Each year CITO's experts in chemistry produce some 15 different examinations for three different levels of Secondary Education. These examinations are still paper-based tests; however, in the near future CBT (Computer Based Testing) examinations will be introduced.

In the chemistry examinations most of the questions are based on a given context, for example presented in the form of:
. a (part of a) newspaper article;
. advertisement leaflets;
. labels with product information;
. an information leaflet for the use of a drug;
. a print of an internet site;
. a scientific article;
. a part of a comic book;
. a "story".

Such a context can be, for example:
. an industrial process;
. an environmental problem;
. a problem from everyday life;
. a scientific problem;
. a "school" problem.

The examinations are made to assess:
. the chemical knowledge of the candidate;
. the chemical skills of the candidate;
. several other skills of the candidate.

75% of the examination assess chemical knowledge and skills and 25% assess other skills, mainly how to use and deal with information. Almost all the items are context based.

1.2 Chemical literacy

The world-wide Organisation for Economic Co-operation and Development (OECD) has a programme to assess to what extent students are literate in science (and other domains), the PISA programme. The PISA definition of scientific literacy is:
"Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity." (See the website www.pisa.oecd.org)
At the Utrecht/ICASE symposium "Teaching for Scientific Literacy" (October 2000) S. Bakker explained that the PISA definition has led to the identification of the following scientific processes:
1. recognizing scientifically investigable questions;
2. identifying evidence needed in a scientific investigation;
3. drawing or evaluating conclusions;
4. communicating valid conclusions;
5. demonstrating understanding of scientific concepts.

In the PISA tests for scientific literacy items should create a real life situation, challenging students to bring in their scientific knowledge to understand a situation, solve relevant problems, develop a standpoint and communicate findings and opinions.
At the same symposium J. Osborne stated that curriculum reform to teach scientific literacy will be ineffective, when there is no knowledge of how to assess literacy skills. (Proceedings of the 2nd International Utrecht/ICASE Symposium, ed. O. de Jong e.a., CD-B press Utrecht University, The Netherlands)
In the chemistry examinations in The Netherlands we operationalize these ideas about literacy into assessment items.
In our opinion we assess chemical literacy when we assess the ability of the candidates in:
. using and dealing with (written) information on a chemical problem;
. using chemical knowledge and skills for understanding information about an everyday problem.
We distinguish the following skills in using and dealing with information:
1. Does the candidate understand the given information?
2. Is the candidate able to select useful information from the given text?
3. Is the candidate able to convert given information into another structured form?
4. Is the candidate able to assess the acceptability or plausibility of information?

We also distinguish skills in argumentation and in determining one's position.
1. Is the candidate able to produce or to recognise valid arguments pro or con a given opinion?
2. Is the candidate able to determine her/his position based on arguments?

This second skills also includes the candidate's possibility to decide on taking action in a real-life context.

Three examples of tasks from the National Chemistry Examinations in the Netherlands are presented below. These tasks are discussed and a conclusion is drawn.
The reader is advised to study the problems first, write the answers down, check and validate the answers with the marking scheme, and then read the commentary.

2. Tasks

2.1 Task 1

2.1.1 Water shortage

Mieke and Rob take a hiking trip for a couple of days. They decide to camp in the forest, but they have a problem. There is no water in the forest and they only brought one litre of water with them in a canteen.
They have bought some lettuce for dinner. The lettuce has to be washed, because it is sandy. They keep the water they used for washing the lettuce in a kettle. The next morning they want to make a drink for breakfast with this water, which contains some sand..
Mieke and Rob can make either coffee or tea, but they do not want to have any sand in it.
The way in which they could prepare the coffee and tea is shown below:

making coffee making tea

2p **1** □ Does the sand in the water not interfere with the preparation of coffee or with the preparation of tea? Explain your answer.

2p **2** ■ Which of the following separation methods is applied in both making coffee and tea?

A adsorption
B distillation
C extraction
D evaporation

2.1.2 Marking scheme

Answers	Partial credit

Water shortage

Maximum score 2

1 □ Sand does not interfere with the preparation of coffee, because the sand remains in the filter.

- the sand remains in the (coffee) filter **1**
- so sand does not interfere with the preparation of coffee **1**

Remark
An answer as: "If you pour the water very slowly and carefully out of the kettle, the sand remains in the kettle. So you can make coffee as well as tea." is a completely correct answer.

Maximum score 1

2 ■ **C** (extraction)

2.1.3 Comment on task 1: Water shortage

This task has been taken from the examination for Junior General Secondary Education in 1998. 17,000 candidates took this examination. The age of the candidates was around 16 and they had received two years education in chemistry.

. It is a story.
. It is a problem from everyday life (In this case it is a special every-day life situation as it is a holiday!).
. It tests the ability to make a decision for a real action.

Candidates recognise the pictures as a usual way in the Netherlands to make coffee or tea. They know that the water passes through a paper filter when they make coffee. When they make tea, the tealeaves stay in a paper (filter) bag, but the water is not filtered.

When answering the first item the candidates have to use the chemical knowledge that solids (sand) remain in a filter. More than one correct answer is possible. The second item tests chemical knowledge.

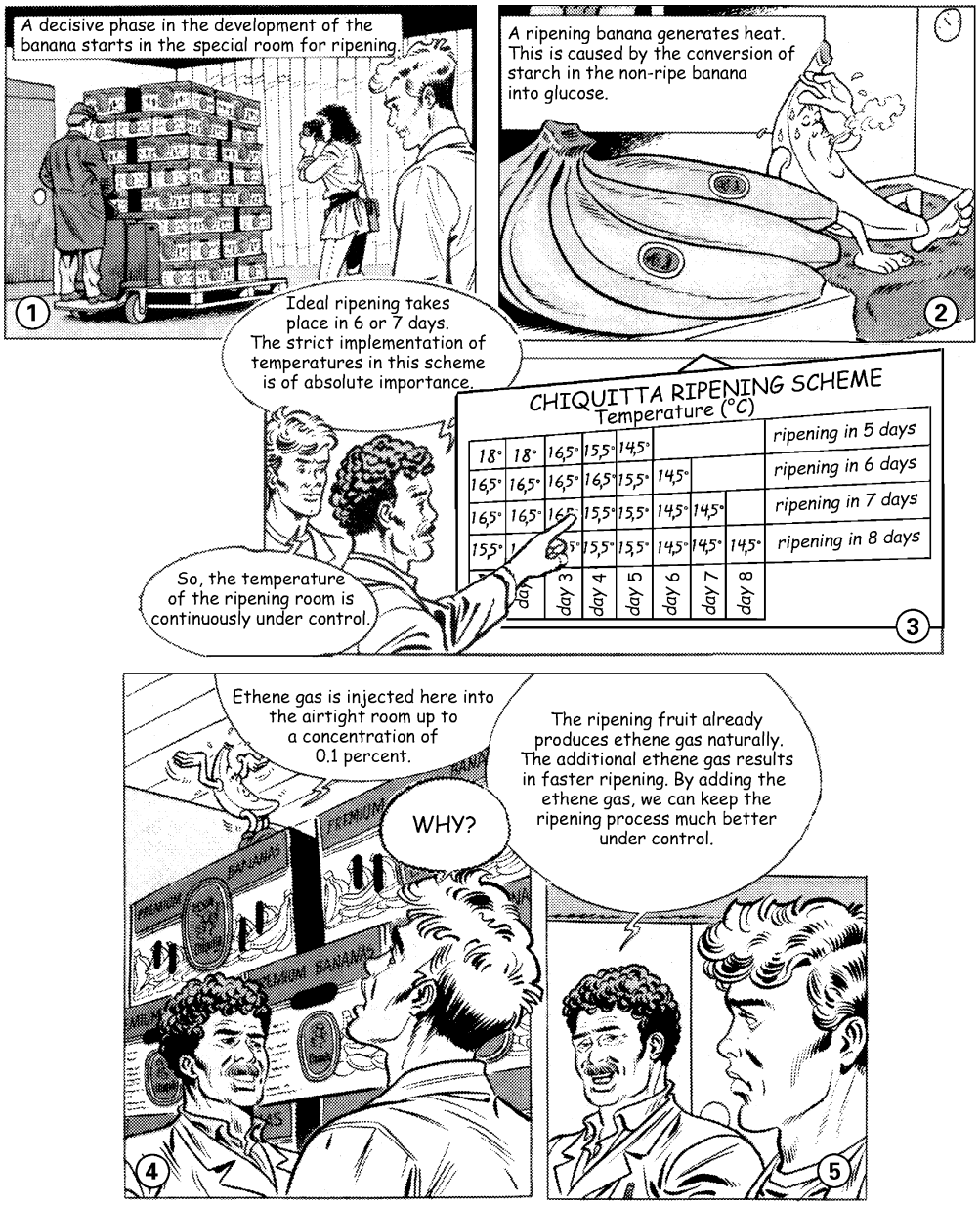
The average p' value of all the items in this examination in 1998 (41 items, total 90 points) was 0,63.
(The p' value of an item is the quotient of the average score of all the candidates and the maximum score)

item	p'	score 2	score 1	score 0
1	0,94	91 %	6 %	3 %
2	0,63	-	63 %	27 %

2.2 Task 2

2.2.1 Bananas

Bananas are harvested when they are still green. After transport to Europe, the green bananas are kept in a special room for ripening. The following part taken from a comic explains what happens in a ripening room.



Adapted from: Chiquita

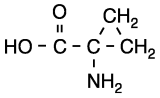
By combining two pieces of information from the comic, it can be deducted that the air in the ripening room has to be cooled to achieve ideal ripening.

2p **1** □ Give these two pieces of information.

The conversion of starch, described in picture 2, is a hydrolysis reaction.

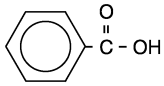
3p **2** □ Give the reaction equation of this conversion. Use molecular formulas; the molecular formula of starch is $(C_6H_{10}O_5)_n$.

Bananas contain substance A.



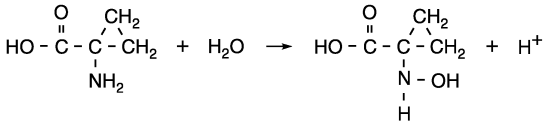
substance A

Compounds as substance A, in which the molecules contain a ring-structure and the -COOH group as a side group, have *-carboxylic acid* as a suffix to their basic name, as for instance benzenecarboxylic acid:



3p **3** □ Give the systematic name of substance A.

The formation of ethene by the ripening banana takes place in two steps. During the first step substance A reacts with an oxidizing agent. Substance B is one of the substances formed in this redox reaction. The equation of the half-reaction of the reducing agent is given here incompletely:



substance A **substance B**

Only the electrons (e^-) and the coefficients are missing in this equation.

3p **4** □ Copy this incomplete equation, put e^- in the correct place and add the coefficients.

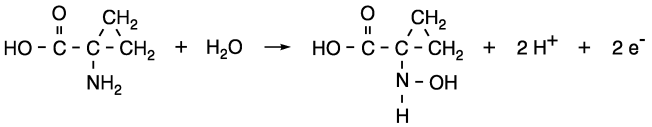
In the second step substance B reacts in molar ratio 1 : 1 with water, which is also present in the banana. Ethene, methanoic acid, carbon dioxide and *one* other substance are formed in this reaction.

3p **5** □ Explain what the molecular formula of this other substance must be. In your explanation, use the molecular formulas of the substances that are involved in the second step.

When the bananas are almost yellow, they are brought to the shop. The shopkeeper has to ensure that further ripening takes place as slow as possible; otherwise the bananas would turn brown. One of the measures he can take is keeping the temperature low, for instance by displaying the bananas in a cool part of his shop. By taking another measure the shopkeeper can ensure that the concentration of ethene around the bananas is as low as possible.

2p **6** □ Give this measure.

2.2.2 Marking scheme

Answers	Partial credit
Bananas	
Maximum score 2	
1 □ • the ripening bananas produce heat	**1**
• according to the ripening scheme the temperature must decrease with time	**1**
Maximum score 3	
2 □ $(C_6H_{10}O_5)_n + n\ H_2O \rightarrow n\ C_6H_{12}O_6$	
• $(C_6H_{10}O_5)_n$ and H_2O prior to the arrow	**1**
• $C_6H_{12}O_6$ behind the arrow	**1**
• coefficients correct	**1**
Maximum score 3	
3 □ 1-aminocyclopropanecarboxylic acid / 1-amino-1-cyclopropanecarboxylic acid	
• 1-amino-	**1**
• -cyclo-	**1**
• propanecarboxylic acid	**1**
Maximum score 3	
4 □ 	
• number of particles C, H, N and O correct	**1**
• e^- behind the arrow	**1**
• number of charges correct	**1**

Maximum score 3

5 □ A correct explanation leads to the conclusion that the molecular formula must be NH_3.

- formula ethene and formula carbon dioxide **1**
- formula methanoic acid **1**
- formula substance B, formula water and conclusion **1**

Maximum score 2

6 □ The shopkeeper must keep his shop well ventilated (so the produced ethene can escape).

If an answer is given like: "make sure that no ethene gets to the bananas" or "keep the bananas dry / free of moisture" **0**

2.2.3 Comment on task 2: Bananas

This task has been taken from the examination for Senior General Secondary Education in 1999. 12,000 candidates took this examination. The age of the candidates is around 17 and they had received three years education in chemistry.

. It is a comic.
. It is about an "industrial" process.
. The last item tests the ability to make a decision for real action.

Candidates have no previous knowledge on this ripening process. They have to use the information in the pictures and the text.

The first item tests the ability to find the "hidden" information. The items 2 to 5 test chemical knowledge and skills. The text between these items also contains information about the ripening process.
In order to answer item 6 the candidates have to imagine the situation in a shop. The item tests the ability to decide on the action to be taken in that situation. 56% of the candidates got no points on this item!

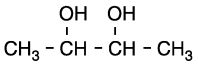
The average p' value of all the items in this examination in 1999 (38 items, total 90 points) was 0,55.
(The p' value of an item is the quotient of the average score of all the candidates and the maximum score)

item	p'	score 3	score 2	score 1	score 0
1	0,61		34 %	55 %	11 %
2	0,48	16 %	33 %	29 %	22 %
3	0,65	38 %	31 %	18 %	13 %
4	0,59	35 %	21 %	29 %	15 %
5	0,52	22 %	30 %	30 %	18 %
6	0,39		35 %	9 %	56 %

2.3 Task 3

2.3.1 Sewage

Sewage (waste water) contains many organic substances. These substances are degraded into carbon dioxide and water.
An oxidant is necessary for this breakdown. Oxygen is the oxidant, in case the sewage is in contact with air. When there is no free O_2 available, sulphate ions, also present in sewage, react as oxidant. The degradation of the organic substances to carbon dioxide and water is a two steps process. In the first step a substance A is formed, with the following structural formula:



substance A

3p **1** □ Give the systematic name of substance A.

In the second step, substance A is degraded into carbon dioxide and water. In this step sulphate ions are converted into sulphide ions (S^{2-}).

3p **2** □ Give the equation of the reaction that occurs when substance A reacts with sulphate, forming carbon dioxide, water and sulphide. You may use the formula $C_4H_{10}O_2$ for substance A.

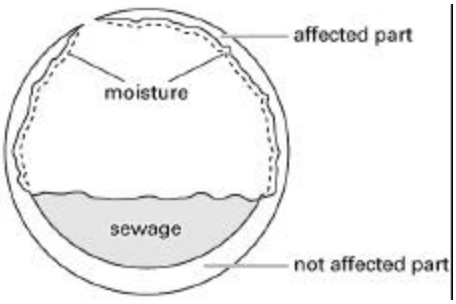
Sulphide is a base. In the sewage, an acid/base reaction takes place: an S^{2-} ion reacts with a water molecule, forming an HS^- ion and one other particle.

2p **3** □ Give the formula of this other particle.

HS^- reacts with water to form hydrogen sulphide (H_2S). Hydrogen sulphide is a gas with a rather low solubility in water. Therefore it escapes from the sewage. With oxygen from the air the hydrogen sulphide is converted into sulphuric acid. The sulphuric acid dissolves in the moisture on the wall of the concrete sewer pipe and in the sewage. Because an acid solution can react with calcium carbonate in the concrete, such a sewer pipe is attacked from within.

3p **4** □ Give the equation of the reaction of calcium carbonate with an acid solution.

The reaction of the acid solution with the concrete causes much damage. The next picture reflects the state of the sewer pipe after several years.



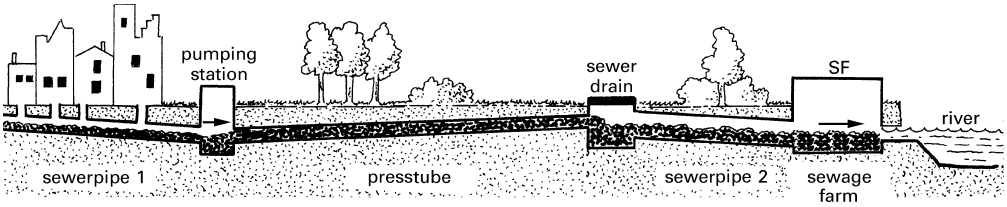
It is assumed that the pH of the moisture in the upper part of the pipe is lower than the pH of the sewage.

2p **5** □ Explain, on the basis of the damage to the pipe, that this is a reasonable assumption.

2p **6** □ Describe how you could verify experimentally in the sewer pipe the correctness of this assumption. Name the material you would need for this verification.

When the sewage, besides sulphate ions, also contains nitrate ions, instead of the sulphate the nitrate is used as oxidant when there is no oxygen present. The nitrate is converted into nitrogen. In this case, no hydrogen sulphide can be formed. For this reason it is expected that the addition of a solution of calcium nitrate to the sewage will prevent damage to the sewage disposal system.

Below, a diagram of a sewage disposal system is given:



The sewer pipes run down slightly and are partly filled with sewage, with air above. The press tube is completely filled with sewage. The last part is a sewer pipe running to the sewage farm.

In the Netherlands they experimented with the addition of calcium nitrate to the sewage. A newspaper has reported about this experiment. Text 1 is a part of the newspaper article.

text 1

Chemical stuff prevents sewer leakage

A chemical stuff will possibly protect the sewers in the Netherlands in the nearby future. The stuff, calcium nitrate, will be used because it might prevent damage to the concrete pipes.
The waste water we produce contains hydrogen sulphide. As soon as this does not find oxygen, it converts itself into sulfuric acid. Sulfuric acid is a mean biting stuff that eats away the concrete.
Because wastewater is pushed through press tubes without oxygen for some time, the production of sulfuric acid is guaranteed. As a consequence the damage to the concrete of the sewer pipe and sewage farm is certain. The answer to this problem is getting near. The addition of calcium nitrate will end this “decay of concrete”, so the sewage purification authority expects.

Source: “De Gelderlander”

Text 1 contains some incorrectness and unclearness.
Line 4 for example suggests that the wastewater that leaves the houses already contains hydrogen sulphide. This is not correct.
In lines 4, 5 and 6, the reporter explains how sulphuric acid can be formed. This description is also incorrect.
From the text of this task, preceding text 1, you can gather how and where hydrogen sulphide and sulphuric acid are formed.

You have to describe correctly how and where hydrogen sulphide and sulphuric acid are formed. The description has to be understandable for someone who does not know much about chemistry. You have to use the following terminology in a correct correlation:
. hydrogen sulphide
. oxygen
. press tube
. sewer pipe
. sulphuric acid

Your description has to replace the *italic* lines in text 1.
Start with: *The waste water we produce <u>does not</u> contain hydrogen sulphide.*
End with: *Sulphuric acid is a mean biting stuff that eats away concrete.*

5p **7** □ Give this description.

It is expected that the addition of calcium nitrate will prevent damage to the sewage disposal system.

2p **8** □ Should the calcium nitrate be added to the sewage in the pumping station, in the sewer drain or in the sewage farm? Explain your answer.

2.3.2 Marking scheme

Answers	Partial credit

Sewage

For the first four questions we just state the correct answers. For the other questions we also describe the marking of partly correct answers.

Maximum score 3

1 □ 2,3-butanediol

Maximum score 3

2 □ $4\ C_4H_{10}O_2 + 11\ SO_4^{2-} \rightarrow 16\ CO_2 + 20\ H_2O + 11\ S^{2-}$

Answers	Partial scores

Maximum score 2

3 □ OH^-

Maximum score 3

4 □ $CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$
or
$CaCO_3 + 2\ H^+ \rightarrow Ca^{2+} + H_2O + CO_2$

Maximum score 2

5 □ In the upper part of the pipe the concrete is affected more, (therefore the reaction rate is higher there,) therefore the moisture is more acidic (than the sewage). (So the pH of the moisture is lower.)

. in the upper part of the pipe the concrete is affected more	**1**
. therefore the moisture is more acidic (than the sewage). (So the pH is lower.)	**1**

Maximum score 2

6 □ An example of a correct answer is:
Measure the pH of the moisture in the upper part of the pipe and of the sewage with a pH-strip.

. measure the pH of both solutions	**1**
. name of an appropriate material	**1**

Maximum score 5

7 □ An example of a correct answer is:
The waste water we produce does not contain hydrogen sulphide. The hydrogen sulphide is formed in the press tube, because the wastewater is without oxygen there for some time. As soon as the wastewater leaves the press tube and comes into a sewer pipe, the hydrogen sulphide comes into contact with oxygen. Then sulphuric acid is formed. Sulphuric acid is a mean biting stuff that eats away concrete.

. it is mentioned that there is no oxygen in the press tube	**1**
. it is mentioned that hydrogen sulphide is formed in the press pipe or that hydrogen sulphide is formed when there is no oxygen available	**1**
. it is mentioned that the sewer pipe contains oxygen (air)	**1**
. it is mentioned that hydrogen sulphide reacts with oxygen into sulphuric acid	**1**
. these four essentials are given in a logical order and fit logically to the given first- and last sentences and there are no formulas in the description	**1**

Maximum score 2

8 □ The nitrate should prevent the forming of hydrogen sulphide (when there is no oxygen / in the press pipe), (therefore it should be added in front of the press tube,) therefore it should be added in the pumping station.

. the nitrate should prevent the forming of hydrogen sulphide (when there is no oxygen / in the presstube) **1**
. conclusion **1**

2.3.3 Comment on task 3: Sewage

This task is from the examination for Senior General Secondary Education in 2000/ New Style. 850 candidates took this (experimental) examination. The age of the candidates is around 17 and they had received three years education in chemistry.

. It is about a text in a newspaper.
. It is about an environmental problem.
. It tests the ability to convert given information into another form (question 7).
. It tests the ability to decide for real action (question 8).

Candidates have no previous knowledge about the processes inside sewage disposal systems. They have to use the information in the pictures and the text.
The first page contains information about the processes. The first four items test chemical knowledge and skills.
The items 5 and 6 test practical skills.
For item 7 the candidate has to imagine a reading public without much chemical knowledge. The item tests the ability to write a chemically correct text for such a public. This type of item was new for the candidates and for the teachers who have to mark the answers.
Item 8 tests the ability to decide in what part of the process real action is needed.
The average p' value of all the items) in this examination in 2000 (37 items, total 90 points) was 0,56.
(The p' value of an item is the quotient of the average score of all the candidates and the maximum score)

item	p'	score 5	score 4	score 3	score 2	score 1	score 0
1	0,75			43 %	44%	7 %	6 %
2	0,61			25 %	38 %	32 %	5 %
3	0,59				57 %	4 %	39 %
4	0,44			16 %	24 %	37 %	23 %
5	0,67				54 %	25 %	21 %
6	0,74				63 %	22 %	15 %
7	0,49	19 %	8 %	16 %	26 %	17 %	14 %
8	0,64				56 %	17 %	27 %

3 Conclusions

It is possible to write items testing “literacy skills”. The three examples are not the only tasks of this kind used in the National Chemistry Examinations in The Netherlands. Each year new ones are written.
These items are closely related to the everyday life situation of the candidates. Our tasks are produced only for candidates in the Netherlands: we make tea and coffee in the way as it was described, we do not have fresh ripe bananas and we have sewer systems with these problems. Perhaps some of these tasks can be used in some other countries, but in most countries of the world the context is quite different from the Dutch context. This means that local teachers can better produce appropriate tasks in context testing “literacy skills” of their pupils.
In the CITO examples some ideas are shown how to write these tasks.

There are many more of these types of tasks in the Dutch examinations, however, the language of these examinations is Dutch. If you are interested, please contact us by e-mail.
When there are enough people interested, we can translate some more tasks and publish these on the CITO website, www.citogroep.nl.