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# Assessment tool for scientific thinking and reasoning skills: an inspiration for university graduates in natural sciences

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## Abstract

*The competencies for the 21st century call for people with a broad and interrelated system of knowledge, skills, values and attitudes for the full application of an individual in personal and professional life. Education, including higher education, focuses therefore not only on the development of knowledge but also on inquiry, critical thinking, analytical thinking, problem solving and decision making. All these skills are often labeled as scientific thinking and reasoning skills. Our long-term research shows that employers from manufacturing and services firms in natural sciences may expect these abilities from their job applicants. However, they often do not find them at the university/high-school graduates seeking for a job. The students have a good domain-specific knowledge of content and basic procedures (in chemistry and biology, among other fields), but they are not able to apply scientific thinking and reasoning skills such as asking precisely formulated questions, drawing conclusions considering all evidence or communicating conclusions properly. This may be due to the fact that they do not have many opportunities to practice such tasks. In order to support both participants/sides, we have developed several tasks for specific positions in companies, such as quality control analyst, quality assurance specialist, or validation specialist. These tasks can serve as a tool for companies to evaluate the skills of scientific thinking and reasoning of employees, as well as tasks that will give the university graduate a clearer idea of the scientific thinking and reasoning skills they must demonstrate during the job interview. A qualitative research study with representatives of manufacturing and services firms in natural sciences was performed: the data collected in structured interviews resulted in a scientific and reasoning framework. This framework and other information from the interviews served as a basis for creating specific tasks. The content and construct validity of the tasks were approved by an expert panel (representatives of the companies) and through pilot testing with a small sample of employees and students. Selected tasks will be presented and discussed in the context of scientific and reasoning skills.*

Keywords: *Scientific Thinking and Reasoning, Task, Science Education*

## 1. Study background

The world has experienced significant changes in the last decades – digital, technological and scientific – which have influenced the labor market, as well as education. Entrepreneurship in today´s economy calls for the creation of new opportunities in an environment characterized by a high degree of complexity and uncertainty; the economy and society focus on innovations [1]. However, such innovations require a greater capacity of human capital - workers with deeper cognitive, technical and soft skills and experiences, in other words, a broad scale of competencies known as 21st century skills. In turn, these requirements put pressure on educational systems that prepare students for their future careers. Therefore, education, including higher education, focuses not only on the development of deeper knowledge but also on inquiry, critical thinking, analytical thinking, problem solving and decision-making [2]. All these skills are often labeled as scientific thinking and reasoning skills in science.

In accordance with Albert Bandura's Social Learning Theory, success in the workplace depends not only on cognitive, technical and behavioral skills but also on an individual's self-efficacy. Self-efficacy is understood as an individual's perception of their ability to achieve a particular task [3]. The question is how self-efficacy can be developed in students during their studies. Coll and Zegwaard [4] argue that authentic work experience may play a key role in the development of graduate competencies contributing to self-efficacy, and such abilities can be developed by combining classroom-based instruction with one or more periods of relevant experiential learning in authentic work settings (e.g., work experience placement). We believe that creating tasks mimicking the real environment of companies in which students can solve problems and situations that commonly occur in such

companies can enhance students' competencies and strengthen their self-efficacy. Solving authentic work tasks can help graduates get a specific job and manage everyday activities and problems they may encounter in their work. Therefore, this approach is beneficial for both graduates and companies.
In our research, we focus on designing tasks related to authentic work problems that improve scientific thinking and reasoning skills of students such as asking precisely formulated questions, drawing conclusions considering all evidence, or communicating conclusions properly. Here, we present such a task (see below, Fig. 1.) based on the scientific thinking and reasoning framework developed in cooperation with selected companies.

## 2. Methodology

In 2019 and 2020, a qualitative research study with representatives of manufacturing and services firms in natural sciences was performed [5]. A prototype of a scientific thinking and reasoning framework, based on methods of theoretical scientific research, was created and discussed with representatives of the firm. This research resulted in a comprehensive framework of scientific thinking and reasoning gathering general scientific thinking and reasoning skills (e.g., identifying a problem, asking precisely formulating question, drawing conclusions considering all the evidence), domain specific scientific thinking and reasoning skills (knowledge of content of the field and knowledge of industry-specific skills) and supporting general abilities and skills (e.g., ability to read and understand scientific texts, ability to write scientific reports, or the ability to present results and convey knowledge to different target groups). Now we have used this framework to create specific tasks proving scientific thinking and reasoning skills. The tasks are based on authentic work problems of firms which were selected by the author of the article based on many years of experience working in several manufacturing and services firms in different work positions. The content validity was approved by an expert panel - representatives of the companies [6] and the construct validity of the tasks was assessed by pilot testing with a small sample of employees - experts and students - novices [7], who checked the quality of the tasks.

## 3. Results

Our research resulted in a set of tasks reflecting authentic work problems of firms. The tasks are set in the context of scientific and reasoning skills, i.e., each of the particular sub-tasks is labeled with a particular set of general scientific thinking and reasoning skills from the scientific thinking and reasoning framework perspective (see the task below). These tasks can serve as a tool for companies to evaluate the skills of scientific thinking and reasoning of employees, as well as tasks that will give the university graduate a clearer idea of the scientific thinking and reasoning skills that they must demonstrate during the job interview. The tasks also provide information to educators, who can include similar topics or tasks in their curriculum. Getting to know authentic problems within the education and the possibility to solve authentic/real tasks can help develop graduate competencies contributing to self-efficacy. Here, we show an example of a task for verifying the ability of students to identify the problem, to formulate an evidence-based scientific hypothesis, to draw conclusions considering all the evidence and to communicate conclusions, including argumentation (Fig. 1.).

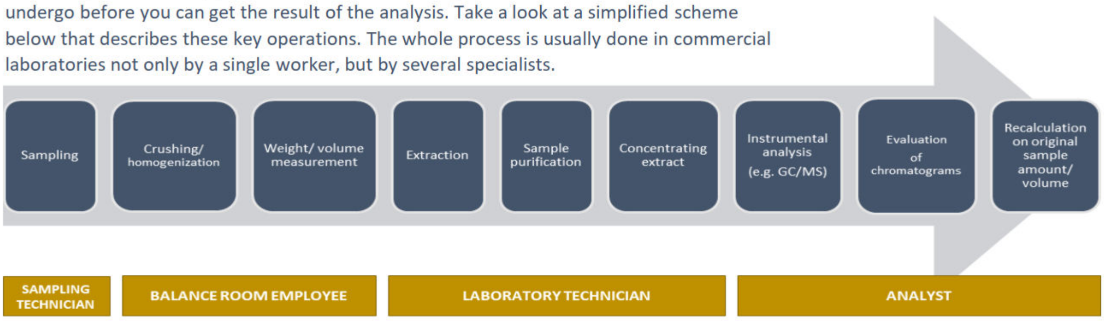
## Laboratory sample and duplicate

**INTRODUCTION:**
You have received a total of 10 samples from the extraction laboratory, which will be analyze using gas chromatography with mass spectrometry detection (GCMS). The order of the analyzed samples in the sequence is given by the standard operating procedure (SOP). According to the SOP, you have created a sequence (see on the right side) and insert the samples to the GCMS instrument. The sequence contains not only analyzed samples, but also control samples (including laboratory duplicates). Last, but not least, the sequence also includes calibration. In order to prevent the so-called carry over effect (transfer of contamination between samples), the so-called flush (f1-f3) is repeated periodically in the sequence, each five samples. This is an injection of pure solvent (n-hexane), which is used to purify the chromatographic system. The flush needs to be included even after the most concentrated calibration point, thus after the calibration is finished. This fifth point in the calibration sequence is marked as Cal_0603_L5. You will measure 2 sets of samples. Each set was prepared separately in the laboratory and includes the appropriate control samples, i. e. one blank, one fortified sample (LCS - Laboratory Control Sample) and a laboratory duplicate (sample name ending with the letters "DUP"). The laboratory duplicate monitors the accuracy of the laboratory analysis starting from the homogenization and weighing of the sample, through extraction to the actual measurement on the instrument. These are always two fractions of the same sample to be analyzed separately by the same procedure. Therefore, in the first set, the laboratory duplicate is marked as VZ_0603_3006_DUP and belongs to sample VZ_0603_3006.

Sequence GC/MS

| POSITION | METHOD | SAMPLE |
|---|---|---|
| Sample 1 | PAH_METHOD | Cal_0603_L1 |
| Sample 2 | PAH_METHOD | Cal_0603_L2 |
| Sample 3 | PAH_METHOD | Cal_0603_L3 |
| Sample 4 | PAH_METHOD | Cal_0603_L4 |
| Sample 5 | PAH_METHOD | Cal_0603_L5 |
| Sample 100 | FLUSH | f1 |
| Sample 6 | PAH_METHOD | Blank_0603_3 |
| Sample 7 | PAH_METHOD | LCS_0603_3 |
| Sample 8 | PAH_METHOD | VZ_0603_3005 |
| Sample 9 | PAH_METHOD | VZ_0603_3006 |
| Sample 10 | PAH_METHOD | VZ_0603_3006_DUP |
| Sample 100 | FLUSH | f2 |
| Sample 11 | PAH_METHOD | Blank_0603_4 |
| Sample 12 | PAH_METHOD | LCS_0603_4 |
| Sample 13 | PAH_METHOD | **VZ_0603_4007** |
| Sample 14 | PAH_METHOD | **VZ_0603_4008** |
| Sample 15 | PAH_METHOD | **VZ_0603_4008_DUP** |
| Sample 100 | FLUSH | f3 |

**TASKS:**
**1.** To complete this task, you will need to know basic operations that the sample must undergo before you can get the result of the analysis. Take a look at a simplified scheme below that describes these key operations. The whole process is usually done in commercial laboratories not only by a single worker, but by several specialists.




Samples from the last set of the sequence are shown on the following picture. It is the sample VZ_0603_0408 and its duplicate VZ_0603_4008_DUP. According to the evaluation of their chromatograms, these samples are not accordant (identic). This indicates a possible error. By checking the vials in the carousel of the instrument, you have verified that the vials have been inserted correctly in the sequence.
**How are you going to proceed? Identify possible cause of the deviation. Scheme of the process (see above) could guide you.**


**Hint n. 1:**
Carefully look at the following photo. The entire last set of samples (blank and LCS are not included) are shown on the photo. What is surprising when doing the visual inspection of the samples? What following procedure would you suggest?


**Hint n. 2:** Choose only one of the following options:

a. I follow the SOP (Standard Operational Procedure). There is clearly defined procedure for this case, which is returning the sample back to the lab for reanalysing (reextraction).

b. I compare the chromatograms of sample VZ_0603_4007 and VZ_0603_4008_DUP over one another. If the chromatograms are matching, the replacement of samples is confirmed. Based on this, I can assign the duplicate to the sample VZ_0603_4007.

c. I follow the SOP (Standard Operational Procedure), but before sending the samples back to lab for reextraction, I verify the homogeneity of the sample at the balance room. I suggest visual control of the sample and its duplicate before insertion to the carousel of the instrument.

d. According to the colours of samples, it could be possible, that duplicate was prepared from sample VZ_0603_4007 by mistake. However, no chromatograms were attached as a proof. Thus, I check the homogeneity of the sample at the balance room and then send the sample to be reanalysed.

Fig.1. Example of a task for scientific thinking and reasoning skills assessment (Note: The hints included in the task are on a separate page; whether the students need to use it or not depends on them.)

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