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

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Lubomíra Pyskatá Rathouská, Svatava Janoušková and Eva Stratilová Urválková

Department of Teaching and Didactics of Chemistry, Faculty of Science, Charles University, Prague, Czech Republic
lubomira.rathouska@natur.cuni.cz, svatava.janouskova@natur.cuni.cz, urvalkov@natur.cuni.cz

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INTRODUCTION

- liquid modernity – uncertainty, complexity, call for innovation [1]
- a broad scale of competencies - 21st century skills
- education: knowledge, inquiry, critical thinking, analytical thinking, problem solving and decision-making [2]; scientific thinking and reasoning skills in science
- our goal: design tasks reflecting authentic work problems and improving scientific thinking and reasoning skills: asking precisely formulated questions, drawing conclusions considering all evidence, or communicating conclusions properly

  See example below: **Laboratory sample and duplicate**

METHODOLOGY

- 2019-2020 a prototype of a scientific thinking and reasoning framework discussed with representatives of the firm.
- a comprehensive framework of scientific thinking and reasoning in natural sciences (see Fig. 1).
- specific tasks proving scientific thinking and reasoning skills were developed
- the content validity was approved by an expert panel - representatives of the companies [3]
- the construct validity of the tasks was assessed by pilot testing with a small sample of employees - experts and students – novices [4], who checked the quality of the tasks

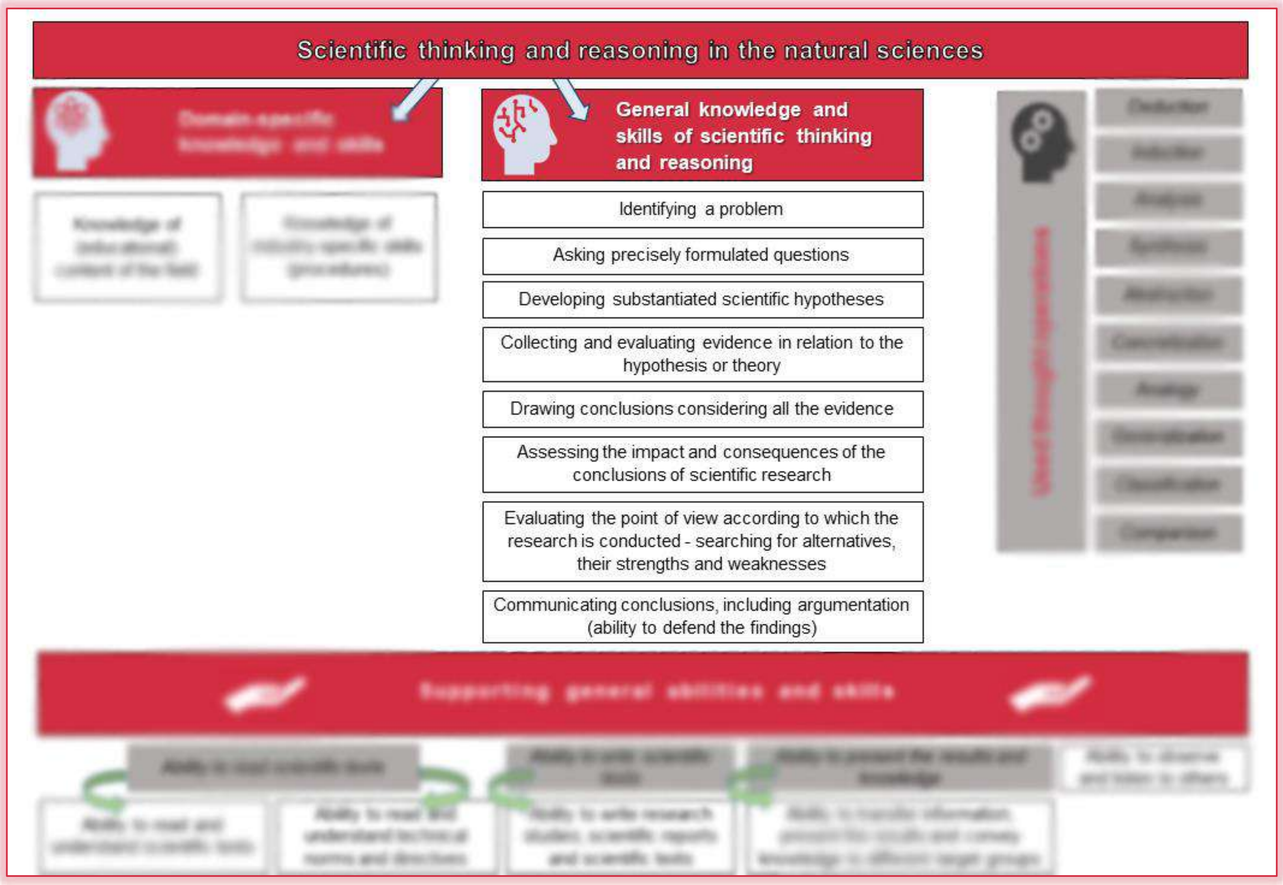


Fig. 1 Framework of scientific thinking and reasoning: the full version is available in a manuscript being under review process now - blurred areas are on purpose

Laboratory sample and duplicate

INTRODUCTION:

You have received a total of 20 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-f5) 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 4 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_1002_DUP and belongs to sample VZ_0603_1002.

POSITION	METHOD	SAMPLE
Sample 1	PAH_METHOD_STAR	Cal_0603_L1
Sample 2	PAH_METHOD_STAR	Cal_0603_L2
Sample 3	PAH_METHOD_STAR	Cal_0603_L3
Sample 4	PAH_METHOD_STAR	Cal_0603_L4
Sample 5	PAH_METHOD_STAR	Cal_0603_L5
Sample 100	FLUSH	f1
Sample 6	PAH_METHOD_STAR	Blank_0603_1
Sample 7	PAH_METHOD_STAR	LCS_0603_1
Sample 8	PAH_METHOD_STAR	VZ_0603_1001
Sample 9	PAH_METHOD_STAR	VZ_0603_1002
Sample 10	PAH_METHOD_STAR	VZ_0603_1002_DUP
Sample 100	FLUSH	f2
Sample 11	PAH_METHOD_STAR	Blank_0603_2
Sample 12	PAH_METHOD_STAR	LCS_0603_2
Sample 13	PAH_METHOD_STAR	VZ_0603_2003
Sample 14	PAH_METHOD_STAR	VZ_0603_2004
Sample 15	PAH_METHOD_STAR	VZ_0603_2004_DUP
Sample 100	FLUSH	f3
Sample 16	PAH_METHOD_STAR	Blank_0603_3
Sample 17	PAH_METHOD_STAR	LCS_0603_3
Sample 18	PAH_METHOD_STAR	VZ_0603_3005
Sample 19	PAH_METHOD_STAR	VZ_0603_3006
Sample 20	PAH_METHOD_STAR	VZ_0603_3006_DUP
Sample 100	FLUSH	f4
Sample 21	PAH_METHOD_STAR	Blank_0603_4
Sample 22	PAH_METHOD_STAR	LCS_0603_4
Sample 23	PAH_METHOD_STAR	VZ_0603_4007
Sample 24	PAH_METHOD_STAR	VZ_0603_4008
Sample 25	PAH_METHOD_STAR	VZ_0603_4008_DUP
Sample 100	FLUSH	f5

TASKS:

1. Look at the last set of the following chromatograms **1A-1C**. Chromatogram of sample VZ_0603_3006 is displayed on *Fig. 1A*. Its duplicate is marked as VZ_0603_3006_DUP and displayed on *Fig. 1B*. The last chromatogram (*Fig. 1C*) should help you with the visual determination of conformity between these two samples.

   How would you evaluate the accuracy of the laboratory analysis? If you rate the accuracy as not sufficient, list the possible causes.

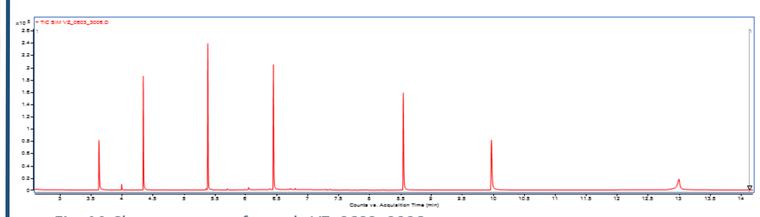


Fig. 1A Chromatogram of sample VZ_0603_3006

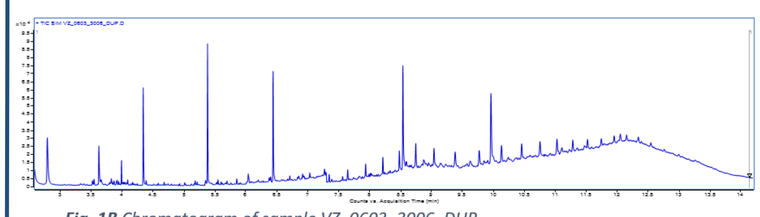


Fig. 1B Chromatogram of sample VZ_0603_3006_DUP

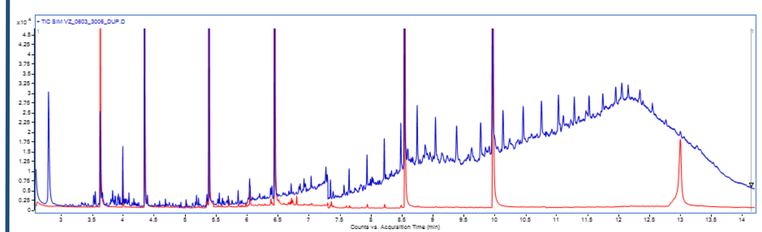
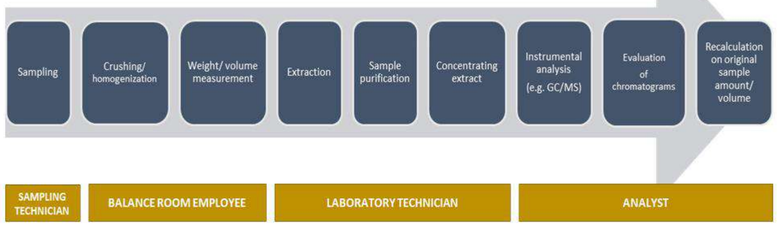


Fig. 1C Zoomed chromatograms of samples VZ_0603_3006 together with VZ_0603_3006_DUP

2. 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 (VZ_0603_4008 and duplicate VZ_0603_4008_DUP). 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 photo of Samples VZ_0603_4007, VZ_0603_4008 and duplicate VZ_0603_4008_DUP on the right. 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.

RESULTS

- a tool for companies to evaluate the skills of scientific thinking and reasoning of employees
- a tool for the university graduates illustrating skills that they must demonstrate during the job interview
- useful tool for educators - similar topics or tasks can be integrated in their curriculum
- solving authentic problems within the education can help develop graduate competencies contributing to self-efficacy

References:
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[2] Turiman, P., Omar, J., Daud, A. M., & Osman, K. (2012). Fostering the 21st century skills through scientific literacy and science process skills. *Procedia-Social and Behavioral Sciences*, 59, 110-116.
[3] Sireci, S. G. (1998). The construct of content validity. *Social indicators research*, 45(1), 83-117.
[4] Huhn, K., Black, L., Jensen, G. M., & Deutsch, J. E. (2011). Construct validity of the health science reasoning test. *Journal of allied health*, *40*(4), 181-186.

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