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# A model for training in analytical chemistry on the basis of technical and personal skills and employment competences

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**ABSTRACT**

*In this paper a model for the development of integrated skills (technical and personal) is applied in Analytical Chemistry exercises and extracurricular activities are considered. During 2013-2015 years sixty students of University of Chemical Technology and Metallurgy (UCTM) were interviewed by a questionnaire on knowledge and academic experience, communication, personal and work skills.*

*The effects were evaluated by external evaluation (by a teacher), self and mutual evaluation by others in the group.*

*The data were processed by standard statistical procedures such as hierarchical agglomerative clustering and non-parametric hypothesis rank tests of matching two samples. The results show that students solve problems applying critical and analytical thinking, experience and knowledge of mathematics and technical subjects, which they associate with their ability to learn and time management.*

*Keywords: analytical chemistry training model, technical and chemical competences, communication and personal skills.*

## INTRODUCTION

Technological and organizational development of businesses sets new requirements to the novice engineers. They should have the opportunity to express and articulate ideas to design, implement, enforce and operate with complex systems and equipment, as well as with the processes in modern team-based environments. Young professionals should be able to participate in the process of engineering, to contribute to the development of new technologies and products, to implement and develop professional standards in different organizations and positions [1, 4, 7].

The requirements of what you are expected to know and able to do are placed by professional organizations and industry. They define the key attributes of the novice engineers in professional fields [3].

Competences describe the knowledge, skills and patterns of future work behavior of the novice engineers with the aim of their successful performance, after completion of training. Bulgarian Chamber of Commerce has developed

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competence models in the sector of chemistry: seventy-five key competences have been described in reference to thirty positions in the chemical industry which have been grouped as functional /technical /, general, leadership and personal skills [15].

Moreover, the assessing and accrediting academic programs expect significant results in terms of knowledge, skills and attitudes of graduate students. Examples of good practice are the engineering associations of Canada and Australia [14, 17].

The study of opportunities, demand and transforming information, the ability to make a choice, adaptation to the environment and its requirements; risk-taking – this means to design personal development and progress in the professional realization of a person. It is necessary to help the young person to do it himself – the teachers to become motivators and associates [12].

A modern solution to the new goals of higher education are integrated educational programs that consist of interconnecting disciplinary courses with planned development of personal and interpersonal skills in relevant scientific and technical areas. An example model for integrated program is: "create-design-perform-function",

*Rethinking Engineering Education: The CDIO Approach* [2] - such a program includes educational activities and experience of students to master the subject knowledge and its application in professional activities.

**Models in the teaching of analytical chemistry**

Modern analytical methods are applicable in many disciplines: chemical science and technology, medicine, biology, environmental protection, industrial sectors and human activity. Almost 50 % of the laws and regulations of the EU require stringent analytical measurements to monitor compliance. The fields of action are constantly expanding - with the development of processes, materials and energy to develop new methods and analysis, create systems for measurement and sensor technology, provides the control and quality management, carry out technical purchases and sales, consulting, and training employees and customers. Analytical Chemistry (AC) as a fundamental and applied discipline requires a multidisciplinary approach and a good cross-sectoral expertise in the various fields-physics, chemistry, mathematics, economics, and law.

The first model for the harmonization of education in analytical chemistry as a chemical subdiscipline is discussed and adopted by the Department of Analytical Chemistry - Division Analytical Chemistry, DAC, of the Federation of European Chemical Societies, FECS – Eurocurriculum, - which meets the recommendations of the chemistry Eurobachelor. In addition to basic and specific knowledge of the discipline, students are expected to develop a wide range of different abilities, skills and competences. They can be divided into three main categories:

- Chemical, related to cognitive abilities and competences,
- Technical/chemical, associated with practical skills,
- General competences.

Miguel Valcarcel recommends to facilitate the transition to EHEA (European higher education area) using two general requirements: focus on the diversity of participants in the learning process-students, teachers, professionals, political and academic authorities and change the culture in the evaluation (new initiatives and innovations), instead of the current exclusive emphasis on scientific knowledge and research activities [11].

**Research on the skills of the students in the new model for education in AC**

A model is set up for training in laboratory practice in developing integrated skills (technical and personal), applied in exercises and extra activities. The aim is to enable students to develop skills in all three categories applying the requirements of the Eurocurriculum II for analytical chemistry, recommended by Division Analytical Chemistry, FECS и European Chemistry Thematic Network (ECTN) [10].

The multidisciplinary nature of analytical chemistry in addition to required specific knowledge, needs such in various areas-nature and science, economics and law, and to the fullest extent in academic preparation and choice of appropriate methods of teaching and learning. In this respect, the expected learning outcomes have been redefined and their corresponding educational activities have been described.

Within the framework of the course, in addition to compulsory disciplinary knowledge, development of abilities, known as employment skills/aptitude (employability) is included. Those who most closely meet the laboratory activities demands are classified into four areas: knowledge and academic experience, communication skills, personal skills and job skills.

A map of these skills has been prepared, with a checklist for self-assessment, peer assessment and co-assessment of the teacher. The evaluation criteria and the level of proficiency are detailed and are available at the beginning of the semester. Problem solving and development of critical and analytical thinking are laid down in the compulsory exercises like hypothesis/concept for analysis, controlling the process by setting the factors and parameters, and it is obligatory to analyze the results at the end of the exercise. Particular attention is paid to the admitted errors, their origin and the way of their minimizing. There are assignments/tasks with different levels of difficulty on the taxonomy of Biggs [6].

The connection of theory and practice is realized with a case study.

Real problems, close to the interests of the students but not realized during the exercises, have been developed. Reporting of results-requirement of GLP (Good Laboratory Practice) is through an oral presentation in front of known and unknown audiences (colleagues and teachers) to develop communication competence and improve personal qualities such as confidence and ability to persuade.

**Testing the model**

A model for development of integrated skills (technical and personal) has been applied in exercises and extra activities in analytical chemistry between 2013 and 2015. With the help of validated questionnaires the profile of students has been illustrated at the beginning of the exercises.

Through the survey studies the following components of the learning outcomes have been evaluated:

1. Mathematics, technical disciplines, analytical chemistry
2. Critical and analytical thinking
3. Ability to link theory with practice
4. Problem solving
5. Ability to create a block diagram of the process in AC
6. Oral report
7. Written report
8. Presentation skills
9. Ability to work in a team
10. Ability to learn
11. Reliability (performance and commitment)
12. Time management
13. Skills for working with electrical appliances and equipment

Respondents were 60 students from five administrative groups and the teachers in AC.

The questions relate to knowledge and skills in the following areas:

- knowledge and academic experience - questions 1-5;
- communication skills - questions 6-8;
- personal skills - questions 9-11;
- work skills - questions 12 and 13.

Each student makes his self-assessment, following the questionnaire, and assess the rest of the colleagues from the group. Self-assessment is labeled with the variables from x1 to x13, and the average assessment of the students from the administrative group by i-th issue of the colleague is labeled with si. The effects for each student is assessed by the teacher for the same issues, variables $y_1, ..., y_{13}$.

The answers to the questions are on a four-point Likert scale and the grade means knowledge/skills/achievements: 4 - high (very good), 3 - medium (good) , 2 - minimal (not good), 1- poor (weak).

**Analysis of the results obtained**

There are tree diagrams (dendrograms) with the standard procedure for clustering (grouping) of variables: teacher evaluation (external evaluation), self-assessment and average student assessment from others in the group (equal in rank), Figures 1, 2 and 3. Data is processed with hierarchical agglomerative procedures of cluster analysis [8, 16].

Clusters are obtained by median method with Manhattan distance (Weighted-pair group centroid (median) method with city-block (Manhatan) distances).

The results, as suggested in Fig. 1 and Fig. 2, show that students solve problems critically and analytically applying knowledge of mathematics and technical subjects, which they associate with their learning abilities and time management.

Fig. 1 is a dendrogram of the AC lecturer assessment at the AH. We distinguish the following groups (clusters) of answers to questions from 1-13:

T1 = {2+4, 7}, T2 = {6+8}, T3 = {9+11}, T4 = {3+5, 10}, T5 = {1+12} and T6 = {13}.

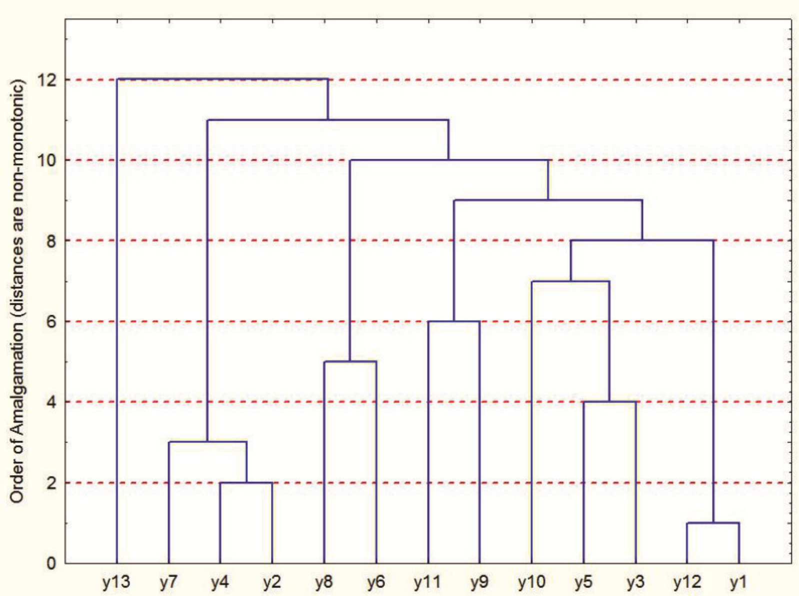


Fig. 1. Dendrogram of the lecturer assessment.

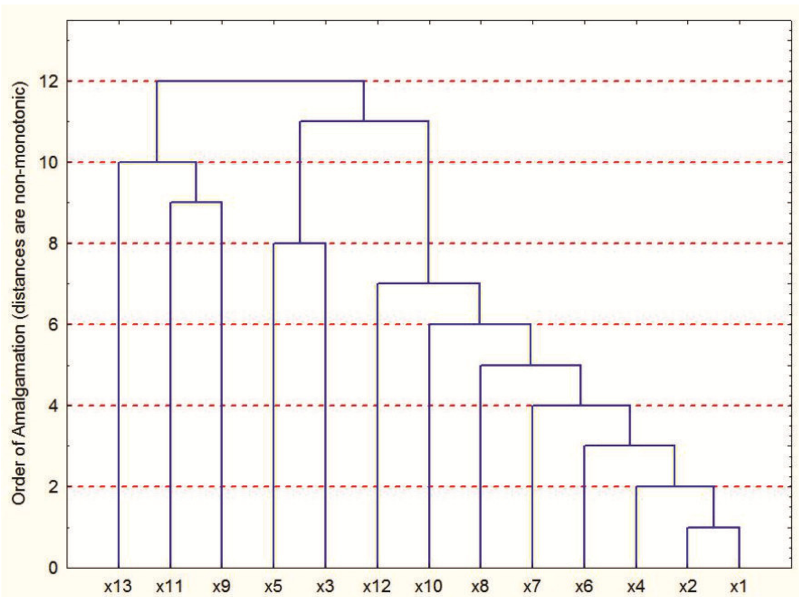


Fig. 2. Dendrogram of the students self-assessments.

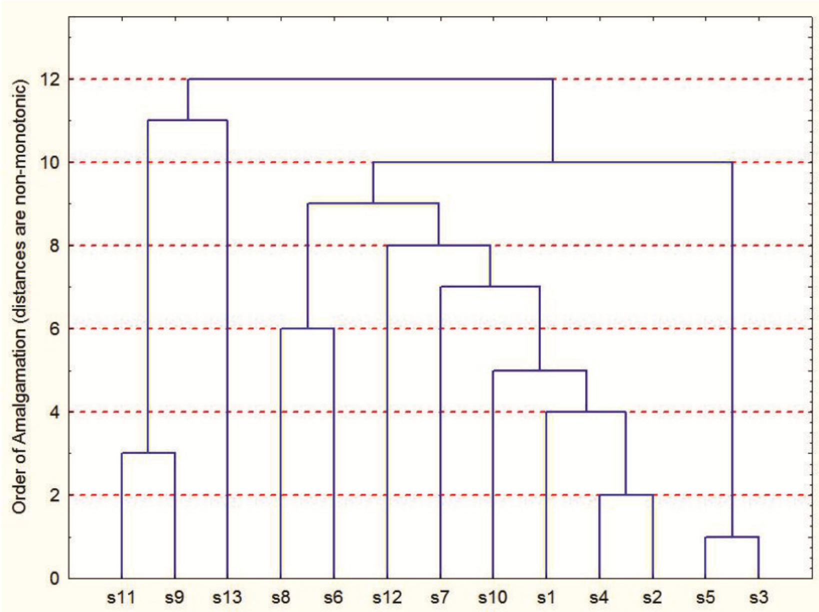


Fig. 3. Dendrogram of the average student assessment.

Fig. 2 is a dendrogram of the students self-assessments. We distinguish the following clusters:

S1 = {1+2, 4, 6, 7, 8, 10, 12}, S2 = {3+5}, S3 = {9+11} and S4 = {13}.

Skills for working with equipment and staff, and S3, S4 are a long distance from the rest of the answers to the questions of the questionnaire.

Fig. 3 is a dendrogram of 13 answers from the cumulative student assessment where you can see 5 clusters: K1 = {3, 5}, K2 = {2+4, 1, 10, 7, 12}, K3 = {6+8} , K4 = {9+11} and K5 = {13}.

Verification of hypotheses about the consistency of responses between teacher and student average assessment has been done [9], (Tables 1 and 2).

From Table 1 (Sign Test for differences between pairs of assessments) we can see that the teacher's assessment does not match with the average student assessment from the following questions: 2, 4, 7, 9 and 11 (critical and analytical thinking, problem solving, written report, capacity for teamwork, performance and commitment).

In Table 2 are given the results of "the stronger" rank-test Wilcoxon Matched Pairs test, which indicates that the evaluation of the teacher does not match with the average student assessment on the following questions: 2-5, 7, 9, 11 and 13, i.e. it is assumed that we have "uniformity" in the assessment between the teacher and students of the group on questions 1, 6, 8 and 12 (knowledge and experience in the technical disciplines, communication skills - oral report, presentation and time management).

Table 1. Sign Test. (Marked tests are significant at $p < 0.05$).

| Pairs | No. of non-ties | % v< V | Z | p-level |
|---|---|---|---|---|
| y1 & s1 | 55 | 45.4 | 0.539 | 0.590 |
| y2 & s2 | 60 | 95.0 | 6.842 | 0.000 |
| y3 & s3 | 59 | 49.1 | -0.000 | 1.000 |
| y4 & s4 | 60 | 93.3 | 6.584 | 0.000 |
| y5 & s5 | 59 | 49.1 | -0.000 | 1.000 |
| y6 & s6 | 58 | 46.5 | 0.394 | 0.694 |
| y7 & s7 | 60 | 95.0 | 6.842 | 0.000 |
| y8 & s8 | 59 | 47.4 | 0.260 | 0.794 |
| y9 & s9 | 60 | 75.0 | 3.744 | 0.000 |
| y10 & s10 | 53 | 56.6 | 0.824 | 0.410 |
| y11 & s11 | 60 | 75.0 | 3.744 | 0.000 |
| y12 & s12 | 52 | 50.0 | -0.139 | 0.890 |
| y13 & s13 | 54 | 55.5 | 0.680 | 0.496 |

Table 2. Wilcoxon Matched Pairs Test. (Marked tests are significant at $p < 0.05$).

| Pairs | Valid - N | T | Z | p-level |
|---|---|---|---|---|
| y1 & s1 | 60 | 694.5 | 0.633 | 0.527 |
| y2 & s2 | 60 | 14.0 | 6.633 | 0.000 |
| y3 & s3 | 60 | 578.0 | 2.317 | 0.020 |
| y4 & s4 | 60 | 15.0 | 6.625 | 0.000 |
| y5 & s5 | 60 | 564.5 | 2.419 | 0.016 |
| y6 & s6 | 60 | 792.0 | 0.491 | 0.623 |
| y7 & s7 | 60 | 14.0 | 6.632 | 0.000 |
| y8 & s8 | 60 | 818.5 | 0.501 | 0.616 |
| y9 & s9 | 60 | 339.5 | 4.236 | 0.000 |
| y10 & s10 | 59 | 450.0 | 2.350 | 0.019 |
| y11 & s11 | 60 | 333.5 | 4.281 | 0.000 |
| y12 & s12 | 60 | 580.5 | 0.988 | 0.323 |
| y13 & s13 | 60 | 346.5 | 3.410 | 0.001 |

## CONCLUSIONS

Students have well constructed ratings for some of the skills they develop in the learning environment. They relatively match the external evaluation of the teacher and reveal similar types of relationships between the components of the learning outcomes.

The most vivid are the examples with the mathematical skills, problem solving, critical and analytical thinking, ability to learn, written report and time management.

When checking the content of assessment data (sign test), the uniformity of lecturer- students assessments on questions 1. 3, 5, 6, 8 10, 12 and 13 receive confirmation. This is data which identifies the requirements towards the environment, so that it can stimulate the skills for independent learning, which supports the development of technical/chemical skills associated with practical and personal skills, or knowledge and academic experience; communication, personal and job skills.

Very indicative is the data for the value of skills (mathematical, technical and time management) that indicates the relevance of the established criteria to the scientific knowledge and skills to operate in a specific environment of tasks, as well as the ability for good organization of activities. But this was not seen with the same force in the self-assessment.

Taking into account the nature of the discipline AC, the data for the link between skills for working with electrical appliances and equipment and all other components of the operation is quite vague. Students associate them with skills for teamwork and reliability, while external evaluation tasks do not take into account the significance of this component of the work and it stays out of the other groups of learning outcomes.

Students show that they need to apply the knowledge and skills to appreciate the linking of theory with practice, and the presentation in the oral report. These are the results of the study, directly job-oriented skills and specific skills for working with electrical appliances and equipment are placed in this group, which, actually, are specific components of the education in AC.

The data from this survey are the basis for optimizing the environment of tasks and the forms for their report. The most serious implications are addressed to the criteria for external evaluation of the lecturer. It essentially follows a more detailed account of the components of the implementation of the tasks (the process of learning and application of skills and knowledge) and not so much the form of a report.

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