Leonardo da Vinci

Education and Culture

Hands-On Approach to Analytical Chemistry for Vocational Schools II

Impact of the hands-on approach in teaching and learning visible spectrometry on students' achievements and its relation with students' motivational orientations and study programs

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Abstract

The evaluation study on the impact of the hands-on approach to visible spectrometry on students' academic performance and its correlation with students' motivational orientations was envisaged as one of the important outcomes of the Leonardo da Vinci project "Hands-on Approch to Analytical Chemistry for Vocational Schools II", LLP-LDV-TOI-2008-SI-15. Altogether, 295 students from Slovenia and Poland took part in the study, while for 104 students from the UK only results of the motivation questionnaire were obtained. The average age of the participating students was 18.2 years – altogether 59% females and 41% males. In order to identify the number of clusters in the data set based on the motivational dimensions defined by controlled and autonomous motivation, *k-mean*s clustering was used. The results revealed two distinct motivational orientations (i.e. profiles): cluster I – low quantity motivation group (with low autonomous and controlled motivation) and cluster II – good quality motivation group with high autonomous and low controlled motivation. Students' cluster membership is reflected in their academic achievements and their attitudes towards the hands-on approach. Students from the good quality motivational group achieved higher scores at the post-test and they expressed more positive attitudes towards the hands-on approach than students from the low quantity motivational group. Apart from students' motivational oritentation, the study program also contributes to the students' academic achievements. Students enrolled in the chemistry technician program with a solid chemistry background achieved the highest scores at the pre-test and post-test respectively. The study also revealed that the hands-on approach supports not only the achievement of better understanding of the concepts taught, but also the capability to apply knowledge in a new situation, and data analysis.

Keywords: evaluation study, hands-on approach, motivational orientation, visible spectrometry

I. Introduction

I.1. Brief Program Background and Context

I.1.1 The program history and goals

Results of the Leonardo da Vinci project “Hands-on Approach to Analytical Chemistry for Vocational Schools” (Project no. SI/03/B/F/PP-176012) with the duration from 10th November 2003 to 9th November 2005, have opened new perspectives for the improvement of teaching and learning of analytical chemistry at the vocational schools. The project promoter was Dr. Nataša Gros from the Faculty of Chemistry and Chemical Technology, University of Ljubljana, and cooperating partners came from: University of Lisbon (PT), Centre of the Republic of Slovenia for Vocational Education and Training (SI), University of Ljubljana, the Department of Chemical Education and Informatics (SI), and University of Hull (UK).

The project met all its goals and targets in terms of outcomes and results. Vocational school sectors, where the hands-on approach to analytical chemistry can contribute to the development of quality education and improvement of vocational training, were identified in participating countries, and expertise in teaching and learning analytical chemistry through hands-on approaches was shared through partners' meetings and related seminars, conferences and workshops. Interested teachers and laboratory assistants were recruited to participate in the project. Five sets of Spektra™ spectrometers for educational purposes (Gros, N. 2004) were produced by a subcontractor and distributed among partners who allocated them further to participating schools in their countries. With the financial support of the Ministry of Education and Sport of the Republic of Slovenia, Slovenian vocational schools for food processing were equipped with additional spectrometers which enabled the teachers to test hands-on approaches developed through this project with entire classes of students. Their responses contributed significantly to the quality of the final products. The small-scale spectrometer, which was introduced into schools through this project for the first time, proved its innovative potential. Even in the modest school laboratory environment it can be easily extended into other analytical instruments, e.g. gas or liquid chromatograph or hyphenated with a computer as demonstrated on the trilingual web page *http://www.kii2.ntf.uni-lj.si/analchemvoc2/* of the project. Another important project result was the trilingual web page “AnalChemVoc” which comprises descriptions of approximately 45 hands-on activities developed by the project partners, participating teachers and their students from all three countries. Another main project result was a handbook entitled “Hands-on Approach to Analytical Chemistry - Manual”, also prepared in all three languages of the project (60 CD copies in each language). The manual which is structured into seven chapters is intended to help teachers to develop self-confidence when dealing with the selected topics of analytical chemistry and using the hands-on approach as an active teaching strategy in their classroom. The last two chapters present two teachers' guides for the introduction of visible spectrometry and chromatography through the hands-on approach. The approach discussed in both teachers' guides was evaluated in several steps, and after each evaluation step the materials were improved. These teachers' guides are related to the teaching units « Hands-on Approach to Visible Spectrometry » and « Hands-on Approach to Chromatography ». They include full support for teacher and students and represent two additional results of the project (not promised in the Application form). These teaching units supplement the Manual on the same CD.

The Manual *“LABORATORIO PORTATIL (KIT)”* was another additioanal product of the project. It is an extended and upgraded version for the new expanded Portable Laboratory, of an old version of the guide book that had been developed for the prior/poorer edition of the “Portable Laboratory”. The Manual was produced for dissemination and use in teaching activities in printed form, A4 size paper, 34 pages and in CD format.

Testing and evaluation of hands-on approaches to analytical chemistry in schools confirmed that the topics as well as the approaches developed and implemented in schools through this project raise interest in students and that the less able students are not left behind, therefore the contents and proposal for teaching approaches developed through the project were introduced into new curricula for vocational schools in Slovenia; however the need for a more in-depth approach in evaluating effects of the hands-on approach in teaching and learning basic concepts of visible spectrometry in relation with students' motivation orientations (i.e.,profiles) was also recognized.

Hands-on approaches based on small-scale instruments were also disseminated through national and international conferences, seminars, workshops and professional journals during the project duration.

As a response to the Call for Applications - 2008 for the Leonardo da Vinci, Lifelong Learning Programme "Transfer of Innovation", a new project has been proposed by Professor Nataša Gros, University of Ljubljana, Faculty of Chemistry and Chemical Technology and 10 partners from Slovenia, Poland and the UK, entitled "Hands-on Approach to Analytical Chemistry for Vocational Schools II". The project, which represents the continuation and broadening the scope of disseminating the results of the previous one, was accepted for financing for the period from 15 November 2008 to 14 November 2010.

I.1.2 The status of the new project

The new project aims at disseminating the results of the previous one, and thus contributing to the better quality and attractiveness of VET (more specifically vocational schools for food processing, chemistry and laboratory medicine) in chemistry-related and chemistry-based disciplines by implementing small-scale low-cost spectrometers that can be easily upgraded into other analytical instruments, e.g., gas and liquid chromatographs, in school practice in Poland, Slovenia and the UK, together with hands-on teaching units and several newly developed hands-on experiments that can increase the motivation in students and contribute to better learning outcomes. Partners from Poland and the UK received the existing teaching units "Hands-on approach to visible spectrometry/chromatography" in English together with a set of low-cost small-scale spectrometers for educational purposes. The Polish partner translated the existing "hands-on" teaching units and experiments from the web page as well as 20 additional experiments developed through this project into the national language. Vocational schools in the Pomerania region, with which the Polish partners have well-established contacts participated in implementing and evaluating the "hands-on" approaches in Polish school practice. The University of Bristol, with its centre of excellence for chemical education, has very well established, extensive, versatile and far-reaching outreach activities for increasing the interest in natural sciences for students at the pre-university level. The UK partner implemented "hands-on" approaches, based on the use of a small-scale, low-cost spectrometer, in its outreach activities. The evaluation study on the impact of the hands-on approach to visible spectrometry on students' academic performance, and its correlation with students' motivational orientations, was also envisaged as one of the important project outcomes.

I.1.1.3 Key stakeholders and partners involved in the program

As the key direct stakeholders of the project, teachers and students of chemistry and related subjects from VET schools in Slovenia, UK and Poland, and as indirect stakeholders those national institutions (e.g. Boards of Education, Ministries of Educations, professional teachers' organizations), which are responsible for designing and implementing new school curricula and new teaching methods in school practice, were recognized. Partners' institutions involved in and responsible for projects' outcomes are: (1) University of Ljubljana, Faculty of Chemistry and Chemical Technology – promoter of the project, (2) University of Gdansk, Faculty of Chemistry, Poland (3) Biotechnical Centre, Naklo, Slovenia, (4) Centre for Biotechnical Education and Training, Ljubljana, (5) Institute for Vocational Education and Training, Slovenia, (6) University of Ljubljana, Faculty of Natural Sciences and Engineering, Slovenia, (7) Secondary School for Pharmacy, Cosmetics and Health Care, Slovenia, (8) Technical Chemistry School Ljubljana, Slovenia, (9) National Education Institute of Slovenia, (10) High School Educational Centre Piramida, Maribor, Slovenia, and (11) School of Chemistry, University of Bristol, UK.

I.2. Scientific background of the evaluation study

Research focusing on theories of knowledge acquisition in the last decades (Chinn & Brewer, 1993; Dreyfus, Jungwirth, & Eliovitch, 1990; Duschl & Gitomer, 1991; Dykstra, Boyle, & Monarch, 1992; Hewson & Hewson, 1984; Niaz, 1995; Posner, 1982; Smith, Blakeslee, & Anderson, 1993) has evoked changes in educational practice. Studies have shown that the traditional textbook and lecture paradigm involving students as passive recipients of facts is not the most effective way to teach (Dykstra, Boyle, & Monarch, 1992; Yager, 1991). By understanding the process of learning, science instruction can evolve into a model in which students become active participants in the development of their own theoretical frameworks. As a practical result of these research efforts a series of student-centred teaching strategies has been introduced in classroom settings, including: group discussions, problem-based learning, student-led review sessions, think-pair-share, student generated examination questions, mini-research proposals or projects, a class research symposium, simulations, case studies, role plays, journal writing, concept mapping, structured learning groups, cooperative learning, collaborative learning, enquiry-based approach, and a hands-on/minds-on approach to teaching and learning. The last two strategies are especially suitable for learning experimental sciences such as chemistry (Vrtačnik, & Gros, 2005, Weawer, 1996,). Flick (1993) defines hands-on science on the one hand as a philosophy guiding the usage of different teaching strategies needed to address diversity in classrooms, and on the other hand as a specific instructional strategy in which students are actively involved in manipulating materials and instruments.

Results of the studies on the effects of thematic, hands-on science teaching and enquiry-based approaches versus the text book approach are contradictory. In the 1990s a large number of American elementary schools started teaching science based on hands-on enquiry curricula. Hands-on performance assessment in which 1000 fifth-grade students were involved from nine school districts in the USA, showed little or no curricula effect, however, it was not completely clear whether the lack of difference in the performance assessments was a consequence of the assessment, the curricula and/or the teaching (Pine et al., 2006). Results of the study in which 18 middle school American students with serious emotional disturbance were instructed over the course of 8 weeks on "Matter" by two different approaches, indicate that students in the hands-on instructional program performed significantly better than students in the textbook program on two of the three measures of science achievements: a hands-on assessment, and a short-answer test (McCarthy, 2005). Also the research findings of O'Neill and Polman (2004) on three different cases of student-centred science activities: the student-designed project work, sustained on-line work with volunteer scientists, and involving students in the formulation of research questions, and data analysis, showed that these activities substantially contribute to the achievement of the scientific literacy goals and competences as promoted in the educational standards.

The study by Chiu, Chou, & Liu (2002) indicates that the positive effects of the hands-on approach in teaching and learning science on deeper understanding of scientific concepts and mastering science competences can be further strengthened by inclusion of the main features of cognitive apprenticeship (i.e. coaching, modelling, scaffolding, articulation, reflection, and exploration) in the hands-on approach. Thirty grade-10 students participated in the study, 10 in the control and 20 in the treatment group. Both groups were presented with a series of hands-on chemical experiments on equilibrium. The students in the treatment group were instructed on the basis of the main features of cognitive apprenticeship, while the control group learned with the tutor without explicit cognitive apprenticeship. The students in the treatment group were able to construct correct models of chemical equilibrium and their achievements significantly outperformed those of the control group.

An additional variable which affects the students' science achievements through the hands-on approach activities is the frequency of exposure to hands-on experience. Data collected by the National Education Longitudinal Study of 1988 in the USA on a nationally representative sample of grade-eight students were analysed in order to find the relation between the amount of time students spent experiencing hands-on science and their science achievements (Stohr-Hunt, 1996). Significant differences were found across the hands-on frequency variable with respect to science achievement. Students who were engaged in hands-on activities every day or once a week scored significantly higher on the standardized test of science achievement than students who were exposed to hands-on activities once a month, less than once a month or not at all (Stohr-Hunt, 1996). Study of the effects of the inquiry-based teacher practices on the science excellence and equity (Von Secker, 2002) shows that teacher practices that improve students' overall academic excellence simultaneously are as likely to contribute to greater inequities among more and less advantaged students as they are to close persistent achievements gaps.

In teaching and learning chemistry, hands-on supported laboratory work is of special importance, due to the abstract language and symbolism of chemistry which calls for establishing links between the theoretical (abstract) and observable (practical) contents of topics taught (Flick, 1993). In addition, through hands-on laboratory work, learning goals such as: subject-matter mastery; improved scientific reasoning, an appreciation that experimental work is complex and can be ambiguous, and an enhanced understanding of how science works, can be achieved (Moore, 2006). The hands-on approach to laboratory work enables also the development of a series of generic competences and skills: manipulation with the equipment, experiment design, observation and interpretation, data collection, processing and analyzing, problem solving and critical thinking, communication and presentation, developing safe working practices, time management, ethical and professional behaviour, application of new technologies and team work (Buntinea et al., 2007).

Nevertheless, according to the contextual paradigm of learning and teaching, it is important to underline also students' personal characteristics, which affect learning; among them, motivation has an extremely important role. Namely, in the last decade motivation has been targeted by teachers, parents and researchers as one of the key factors determining whether or not students have succeeded at school. The central focus on motivation research is therefore on the conditions and processes that facilitate the persistence, performance, healthy development, and vitality of our endeavours.

Research is fairly consistent in showing that motivation influences cognitive and metacognitive processes amongst students and thus stimulates higher forms of thinking and determines the individual's attitude and approach to learning and to activities that lead to (learning) creative achievements (e.g., Jarvela, & Niemivirta, 2001; Schunk, & Zimmerman, 2008).

Rheinberg (Rheinberg, Vollmeyer, & Rollett, 2000) explains the influence of motivation on learning more precisely, on three levels: (1) on the level of the time that the student dedicates to learning or to learning tasks, both in the sense of the extent (duration) and frequency of the execution of learning activities, (2) on the level of the forms, or nature, of the learning activities, which, on the one hand, is a case of balancing the effort that the student invests in learning (in relation to the level of difficulty of the learning task), while, on the other hand, it concerns the use of learning strategies that will stimulate the student to learn and with which the student will effectively achieve his or her learning goals (superficial learning or learning for understanding), and (3) on the level of the student's functional disposition, which is based on the optimal psychological state of the pupil while learning, that is, the state of internal motivation in Csikszentmihalyi's sense; in this state, learning proceeds in the most qualitative way (see Figure 1)

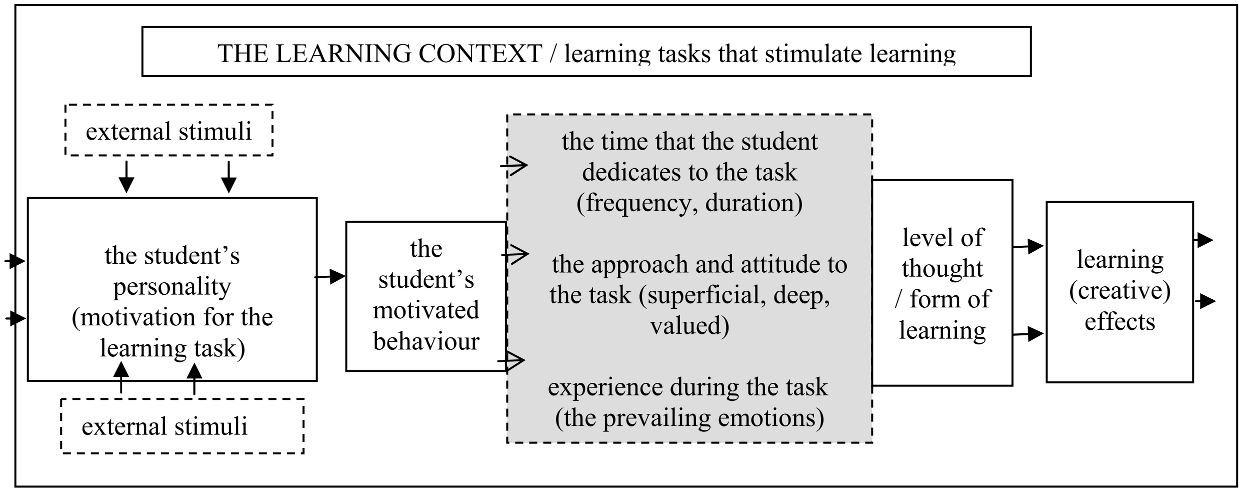


Figure 1: The dynamics of motivation in the process of learning (after Rheinberg, Vollmeyer, & Rollett, 2000).

Most theories have treated motivation as a unitary concept that varies in amount (Deci, & Ryan, 2008), however, by contrast, the Self Determination Theory (SDT) of motivation (Deci, & Ryan, 2000; Ryan, & Deci, 2000) has revealed new insights and dimensions of motivation. The theory focuses on the motivational orientations or types, rather than just the amount, of motivation, paying particular attention to autonomous motivation, controlled motivation, and motivation as a predictor of performance, relational, and well-being outcomes (Deci, & Ryan, 2008). Motivation is thus defined as a multidimensional concept that varies in terms of quality. Student motivation is of high quality when primarily based on autonomous motivation, i.e. intrinsic, identified and integrated regulations, and it is of poor quality when based on controlled motivation, i.e. external and introjected regulations (Guay, Ratelle, & Chanal, 2008).
A series of research outcomes have proven that autonomous academic motivation is positively associated with academic achievements (e.g. Fortier, Vallerand, & Guay, 1995; Grolnik, Ryan, & Deci, 1991; Guay, & Vallerand, 1997; Ratelle, Guay, Vallerand, Larose, & Senécal, 2007).

In addition, research findings (Guay, Chanal, Ratelle, Marsh, Larose, & Boivin, 2008) have revealed that some types of motivation were subject specific, whereas others were not; for example intrinsic motivation differed in intensity for maths, writing, and reading. Furthermore, autonomous motivation has been found to be more in evidence when students experience satisfaction of their basic psychological needs for competence, relatedness, and autonomy. Examination of different aspects of SDT in the domain of education by Deci, Swartz, Sheinman, & Ryan (1981), Chirkov, & Ryan (2001), Vansteenkiste, Simons, Lens, Sheldon, & Deci (2004) has shown that in classrooms in which teachers were autonomy-supportive, students were more intrinsically motivated, they also felt more competent at school work, and so they had a higher self-concept. The autonomy-supportive style of teaching also led to greater learning performance outcomes than did the controlling style. The autonomy-supportive style of teaching is primarily related to a relaxing classroom atmosphere, which according to neuropsychological research studies is crucial for effective learning to occur. Information associated with positive emotions is assimilated through the hippocampus and further processed in the cerebral cortex, while the information associated with negative emotions is assimilated through the amygdale. The amygdale conditions the organism when quick reactions are needed, for instance in situations that involve conflicts, or fleeing. Therefore, the amygdale is not of help when recalling experiences and factual knowledge, or when knowledge is processed (Aggleton, &Young, 2002; Phelps, 2006; Stone, Baron-Cohen, & Knight, 1998).

I.3 Rationale /the need for the evaluation/ of the study

Rapid technological development requires professionals with excellent analytical chemistry skills to monitor technological processes and their impact on the environment, and to control food safety and people's health. Vocational education in Europe, especially in chemistry-based and chemistry-related disciplines, is undergoing a crisis, as reflected in low enrolment rates, under-funding causing a lack of adequate analytical instrumentation, changes in structure and the motivation of students. A low cost spectrometer Spektra™ which was introduced through the implementation of the project "Hands on Approach to Analytical Chemistry for Vocational Schools II" in Slovenian, Polish and the UK schools, and teaching units based on the hands-on approach to teaching and learning basic concepts of visible spectrometry and chromatography are aimed at overcoming some of the above mentioned problems. However, in order to ensure broader dissemination and further upgrading of the proposed approaches as well as acceptance by the teachers, a research study is needed on the impact of the hands-on approach to visible spectrometry on students' academic achievements (knowledge) as well as the relation of the achievements to students' motivational orientations. Recommendations for teachers made from the results of the study would encourage teachers to use the hands-on approach in teaching analytical chemistry more frequently and with greater self-confidence.

I.4 Objectives of the study

The general evaluation question was to identify students' motivational orientations based on the values of autonomous and controlled motivation.
Specific questions were:

- to study the impact of students' motivational orientations on their:
  - academic achievements at pre-test and post-test,
  - prior knowledge (grades in science subjects),
  - attitudes towards different didactical aspects of worked modules through the hands-on approach towards visible spectrometry,
  - attitudes towards specific knowledge and skills gained through the hands-on approach towards visible spectrometry,
  - attitudes towards handling the spectrometer Spektra™ and other materials used,
- to study the impact of the vocational school study program (school) on students':
  - achievements on pre- and post-test,
  - attitudes towards different didactical aspects of worked modules,
  - attitudes towards specific knowledge and skills gained through the hands-on approach towards visible spectrometry,
  - opinions on handling the spectrometer Spektra™ and other materials used,
- to assess the impact of the hands-on approach on the quality of knowledge gained,
- to obtain teachers' opinions about the suitability of the didactical design of the modules, on visible spectrometry and supporting materials (Workbook for Students and Teacher's guide) for application in the classroom,
- to obtain teachers' suggestions and proposals for changes in the design of the modules in order to achieve better learning outcomes.

II Evaluation Approach and Method

II.1 An overview of how the evaluation was conducted, the expected data collection and analysis methodologies for the evaluation

At the first partners' meeting held at the Faculty of Chemistry and Chemical Technology, University of Ljubljana from 10 to 11 November 2008, four modules from "Hands-on Approach to Visible Spectrometry" (Gros, Vrtačnik, & Camões, 2005) were selected for the purpose of the evaluation study. The structure and instruments of the evaluation study were presented and agreed upon, and the standardization procedure discussed. In December 2008 the first draft of the test for motivation and attitudes, and questionnaire for teachers were prepared, and in January 2009 the final versions of the motivation test and teacher's questionnaire, together with pre-test and post-tests, were disseminated to the partner P0 for the final inspection. From January till mid April 2009 a standardization procedure of the instruments took place at two Slovenian vocational and technical high schools, Biotechnical School Naklo (8 students), and Educational centre Piramida, Maribor (41 students), who volunteered for this task. Based on the results of the standardization, the pre-test and post-test were amended and translated into English and through the project web page made available to the partners from the University of Gdansk, and School of Chemistry, at the University of Bristol together with the test for motivation and attitudes, and teacher's questionnaire. From May 2009 till June 2010 the final phase of the evaluation procedure was conducted, in which a total of 406 students (93 from Poland, 104 from the UK and 209 from Slovenian vocational and technical school) took part (see Table 1).

Table 1
Participation of students in the semi-standardization[1] and final evaluation study

Instruments applied	School	N
	Biotechnical School Naklo	8
	Educational Centre Piramida Maribor	41
		Σ=49
Final evaluation		
Motivation test only	School of Chemistry, Bristol (Schools:BTSS, UCEC,SLPD)	104
All instruments	University of Gdansk, Poland (technical High School)	93
	Secondary Education Centre, Ljubljana - general programme	19
	Technical Chemistry School, Ljubljana	36
	Centre for Biotechnical Education and Training, Ljubljana, Biotechnology program, class 2009	31
	Centre for Biotechnical Education and Training, Biotechnology program, class 2010	50
	Educational Centre Piramida Maribor	28
	Secondary School for Pharmacy, Cosmetics and Health Care	27
	Biotechnical Centre Naklo, class 2010	18
	Total	**Σ = 406**

[1] Only 49 students took part in the standardization, therefore test items could not be evaluated by an extended statistical approach. Frequencies of test items were used as criteria for accepting or omitting a particular test item.

For the purpose of the students' motivational orientations (i.e. profiles) identification data were analysed by the *K-nearest* clustering procedure. To establish the relation between independent and grouping variables, a t-test and ANOVA were carried out after Levene's Test for Equality of Variances was performed using the SPSS statistical programme, version 17.0.

II.2 Instruments used in the study

A 50-item questionnaire for assessment of students' motivation and attitudes towards the hands-on approach to visible spectrometry was constructed on the basis of two questionnaires used in previous research (Black and Deci, 2000; Juriševič, Razdevšek Pučko, Devetak, & Glažar, 2008) with the theoretical background from educational psychology research on motivation and self-concept (Deci, & Ryan, 2000; Marsh, 1990). Specifically, the instrument was designed to assess: (1) different components of students' motivation for learning chemistry (i.e., controlled motivation based on extrinsic motivational stimuli, regulated motivation based on internalized and integrated motivational stimuli, intrinsic motivation, and academic self-concept), (2) students' reasons for preference regarding the instructional method used in the study, and (3) students' preferences for different learning methods usually applied in chemistry classrooms. Administration of the instrument takes approximately 15 minutes in the classroom; students are asked to respond to a simple declarative sentence on a 5-point Likert scale, ranging from 5 - very true for me, to 1 - not at all true for me. For assessment of the impact of the hands-on approach to visible spectrometry on knowledge, a pre-test (with 12 short items, total scores 5.75) and a post-test (with 20 short items, total scores 10.75) were designed and semi-standardized. The concepts included in both tests are presented in Tables 22 and 23, respectively. A teacher's questionnaire was designed to obtain teachers' responses regarding: (1) their preferences towards different teaching strategies, methods, and students' knowledge assessment used in the classroom (19 items), (2) their opinions and observations during the practical work with the selected modules and teaching materials (32 items), (3) comments and proposals for enhancement (four open-ended questions). A 5-point Likert scale was used, ranging from 5 - always to 1- never, in the case of the responses regarding preferences towards teaching methods and strategies, and from 1- not at all true to 5- very true for me, in the case of responses regarding opinions and observations during the practical work.

III Evaluation Work Structure and Timetable

III.1 The area and population to be considered, national/regional

Taking part in the evaluation study were Slovenian and Polish students from vocational and technical high schools, more specifically vocational schools for food processing, chemistry and laboratory medicine, and pharmacy, cosmetics and health care. From the UK, students were involved in the outreach activities organized by the School of Chemistry, at the University of Bristol: Bristol Trinity Summer School, University Chemistry Experience Camp, and Schools Laboratory Programme Day. The average age of the participating students was 18.2 years - altogether 59% females and 41% males.

III.2 The program and period of the program performance to be evaluated

The program performance to be evaluated consists of four modules selected from the "Hands-on Approach to Visible Spectrometry: Module 3 – Colour of substances and light transmittance, Module 5 – Measurement of Light Transmittance, Module 6 – Spectrometric determination of concentration, and Module 7 – Practical application of visible spectrometry.

The basic aims of the selected modules were to introduce to the students through the hands-on approach the following concepts and procedures:

- relationship between the colour of a substance and transmittance of light of different colours,
- selection of the correct light emitter for measuring the transmittance of light through a coloured medium,
- the concept of transmittance (T) as a ratio between the radiation power transmitted by the absorption medium (ϕ) and the radiation power incident on the absorption medium (ϕ_o),
- transmittance measuring procedure in various absorption media (filter foils, coloured liquids), and the role of a blank,
- experimental development of the Lambert-Beer's Law,
- application of visible spectrometry for determination of the concentration of a substance in real samples,
- the importance of calibration in spectrometric analyses,
- the difference between single-point and multiple-point calibration.

Each module is supported by the teacher's guide, student's workbook and PowerPoint support, which enables teachers to control the students' performance of the experiments included in the modules, and to provide immediate feedback on the correctness of students' interpretation of the experimental results. The estimated time for the execution of the selected modules, which was established already in the previous study, is 8 h (45 minutes each). The evaluation started in January 2009 (standardization of the instruments) and ended in June 2010. Teachers from the participating schools were free to select within the defined time span, the exact date when they would start presenting the modules and submitting tests.

III.3 Tasks that organize the work into an efficient structure by which the evaluation was managed and monitored

The modules which were subjected to the evaluation procedure had been designed and developed by N. Gros (Faculty of Chemistry and Chemical Technology, University of Ljubljana) and M. Vrtačnik (Faculty of Science and Engineering, University of Ljubljana), during the course of the previous project AnalChemVoc (2003-2005), and were distributed to the participating partners or directly to the schools on the CD entitled "Hands-on Approach to Visible Spectrometry".

Slovenian and English versions of the pre-tests and post-tests were prepared in co-operation with M. Vrtačnik (P5 University of Ljubljana, NTF-KII) and the promoter of the project N. Gros (P0 University of Ljubljana, FKKT). The motivation test and questionnaire for teachers were prepared by M. Juriševič, from the Faculty of Education, who is the sub-contractor of the project, and M. Vrtačnik (P5). The Polish partner M. Kwiatkowski from the University of Gdansk (P1) was responsible for the translation of the modules and all instruments, selection and attraction of Polish high school teachers to participate in the evaluation study, while the English partner T. Harrison, University of Bristol (P10) was responsible for attracting high school students from his region into the project. The harmonization of raw data and statistical data analysis and interpretation was done by M. Vrtačnik (P5) in cooperation with M. Juriševič. The responsibility for the preparation of the evaluation study together with recommendations remains the responsibility of partner 5.

III.4 Conducting research at the participating schools

Prior to the practical work with the modules, teachers had to prepare copies of the selected modules from the student's workbook and copies of the tests. Each test had to be assigned with the unique students' code. One hour before the start of the first module, a pre-test was administered. In the next hour teachers started to work with the selected modules from the unit “Hands-on Approach to Visible Spectrometry. The recommendation was to execute modules in the following order 3, 5, 6 and 7. But some teachers omitted module 3 and some module 6. Students were provided with the appropriate hand-outs from the Workbook, and divided into small groups (3 to 4 students). Each group was equipped with the instrument spectrometer Spectra^{TM} and all the necessary reagents and other materials. Teachers were free to decide how much time they would devote to a particular module. However, they had to make sure that at the end of each module they gave students time to answer some questions which were at the end of each module, because these questions were meant for checking understanding of the concepts. After completion of the modules a post-test was submitted, followed by the motivation test. Slovenian teachers sent all tests directly to the partner P5, while the Polish and English partner input data into the pre-pared Excel table which was e-mailed to the partner P5 for further harmonization and data analyses.

IV Results

IV.1 Demographic and other study coverage data

The data set which was finally included into statistical analysis for the purpose of the evaluation study was reduced from 406 to 295 cases (i.e. participating students), due to missing data. Only those schools from which all the instruments were duly handed out to the partner P5, were subjected to the final analysis.
Students from the UK did not work with the proposed modules, therefore only the partially filled in motivation test was provided on time. The evaluation study includes 92 test results from Polish vocational high school students and 203 test results from Slovenian vocational school students.

Table 2
Reduced data set of students

Institution:	N
Technical High School, Poland	92
Secondary Education Centre, Ljubljana – general program	19
Technical Chemistry School, Ljubljana	36
Secondary Education Centre, Ljubljana – Biotechnology class 2010	45
Secondary Education Centre, Ljubljana – Biotechnology, class 2009	30
Educational Centre Piramida, Maribor	28
Secondary School for Pharmacy, Cosmetics and Health Care	27
Biotechnical Centre Naklo	18
Total	**295**

For students from the UK only motivational orientations were identified and this result is reported separately, at the end of the section.

IV.2 Study findings and outcome data

IV.2.1 Students’ motivational orientations and their impact on academic achievements

In order to identify the number of students’ motivational orientations (i.e. clusters) in the data set based on the motivational dimensions defined by controlled and autonomous motivation - more specifically, intrinsic, regulated, controlled motivation and self-concept - *k*-means clustering was used.
The means for each cluster on each dimensions and *F* values from the analysis of variance on each dimension were used as indications for assessment of how distinct different *k* clusters are (StatSoft, 2010).

The greatest differences between means for three of the four dimensions of clustering from the analysis of variance performed for each of the dimensions, were obtained for the *k*-2 clustering procedure. Therefore, in further analysis, we decided to use the results of *k*-2 clustering of the data set based on four dimensions (intrinsic motivation, self-concept, controlled and regulated motivation). The final cluster centers and number of cases in each cluster are presented in Table 3.

Table 3
Final Cluster Centers

	Cluster	
Dimension	I	II
Intrinsic motivation	2.18	3.61
Regulated motivation	2.80	3.87
Controlled motivation	2.98	3.01
Self-concept	2.45	3.87
No. of cases in each cluster	163	132

Based on the values of autonomous motivation (i.e. $M_{intrinsic} = 2.27$, and $M_{regulated} = 2.86$) and controlled motivation (M = 2.99), cases in cluster I could be identified as a low quantity motivation group (i.e. low autonomous, low controlled) while members of cluster II as a good quality motivation group (i.e. high autonomous and low or average controlled motivation) (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009).

The impact of motivational cluster membership on academic achievements, prior knowledge and knowledge of concepts from visible spectrometry, gained through the hands-on approach, is shown in Tables 4 and 5, respectively. In Table 4 group statistics of the achievements on the pre- and post-test are presented, and in Table 5, statistical significance of differences between means of two groups of students regarding their motivational orientation.

Table 4
Descriptive Statistics – pre-test, post-test results and prior academic achievements for the motivational orientation of students

	Cluster Number of Case	N	M	SD
Pre-test	I	163	64.44	17.57
	II	132	68.64	20.84
Post-test	I	163	59.63	20.60
	II	132	69.63	20.23
Prior academic achievement	I	72	3.32	.85
	II	81	3.75	.75

A statistically significant difference between the low quantity and good quality motivation groups of students at the α-level of 1% was found for achievement on the post-test, and at the α-level of 5% for prior academic achievements, while on the pre-test the difference between groups is not statistically significant (see Table 5).

Table 5
Differences between groups in the pre-test, post-test results and prior academic achievements (t-test)

	t	df	Sig. (2-tailed)
Pre-test	-1.88	293	.061
Post-test	-4.18	293	.000
Prior academic achievement	-3.35	151	.001

IV.2.2 Impact of students' motivational orientations on their opinions about the hands-on approach to visible spectroscopy

We were further interested in the impact of the two motivational orientations on students' opinions on: (1) **different didactical aspects** of the hands-on approach towards visible spectrometry, i.e. suitability of the workbook and teacher's intervention, group work, relaxing climate, learning impact, hands-on approach in carrying out experiments; (2) contribution of worked modules to **specific knowledge and skills ,** i.e. understanding the correlation between colour of matter and absorption of light, selection of LED for measuring the transmittance of the absorption medium, relation between transmittance and absorbance, application of visible spectrometry in determination of concentration, (3) **handling the instrument**, **materials and safety**, i.e. easy work with Spektra^{TM}, clear description of the procedures, possibility to observe experimental results from very close, easy handling of the laboratory materials, standard equipment not necessary, low impact on personal health and environment.

1. *Differences between motivational groups in opinions on different didactical aspects of presenting concepts from visible spectrometry through selected teaching modules*

Group statistics on opinions of the low quantity (cluster I) and good quality motivation group (cluster II) of students on didactical aspects of the worked modules are displayed in Table 6, and the statistical significance of differences between the two groups in Table 7.

Table 6
Descriptive Statistics – students' opinions on different didactical aspects of the worked modules from spectrometry

Didactical aspects	Cluster Number of Case	N	M	SD
Workbook	I	144	3.16	1.11
	II	119	3.33	1.19
Teacher's support	I	144	3.36	1.07
	II	119	3.76	1.13
Group work	I	144	2.64	1.16
	II	119	3.19	1.34
Relaxing climate	I	144	3.67	1.03
	II	119	3.87	1.21
Enhancement of understanding	I	144	3.54	1.12
	II	119	4.07	1.02
Hands-on approach	I	142	3.08	.96
	II	118	3.67	1.05

Table 7
Differences in students' opinions on different didactical aspects of the worked modules on spectrometry (t-test)

Didactical aspects	t	df	Sig. (2-tailed)
Teacher's support	-3.6	261	.000
Relaxing climate	-3.94	261	.000
Enhancement of understanding	-4.67	258	.000
Hands-on approach	-3.11	260	.002

2. Differences between motivational groups in students' opinions on specific knowledge and skills gained through the hands-on approach

Group statistics of students' opinions from the low quantity (cluster I) and good quality motivation group (cluster II) on the impact of the hands-on approach to visible spectrometry on knowledge and skills gained through the hands-on approach as experienced with worked modules are given in Table 8, while the results of t-test for statistical significance of differences are shown in Table 9.

Table 8
Descriptive Statistics – knowledge and skills gained

Specific knowledge and skills	Cluster Number of Case	N	M	SD
Colour of matter and absorption of light	I	144	2.91	1.04
	II	119	3.66	1.11
LED selection	I	144	3.20	1.05
	II	119	4.24	3.82
Understanding the role of the blank	I	144	3.42	1.12
	II	119	3.92	1.08
Handling the instrument Spectra^{TM}	I	144	3.55	1.06
	II	118	3.90	1.16
T / *A* relation	I	144	3.11	1.02
	II	119	3.75	1.09
Impact on self-confidence	I	143	3.06	1.04
	II	119	3.57	1.14
Spectrometry usage	I	144	3.22	.99
	II	119	3.97	.95

Table 9
Differences in the students' opinions on knowledge and skills gained (t-test)

Specific knowledge and skills	t	df	Sig. (2-tailed)
Colour of matter and absorption of light	-5.61	261	.000
	-5.58	245.57	.000
LED selection	-3.13	261	.002
	-2.89	132.89	.005
Understanding the role of the blank	-3.66	261	.000
	-3.68	254.60	.000
Handling the instrument Spektra^{TM}	-2.54	260	.012
	-2.52	240.60	.012
T/A relation	-4.89	261	.000
	-4.86	244.48	.000
Impact on self confidence	-3,83	260	,000
	-3.79	241.77	.000
Use of spectrometry for determination of concentration	-6.17	260	.000
	-6.20	253.12	.000

3. *Differences between motivational groups in their opinions on handling the instrument, materials and safety*

Group statistics of students’ opinions from the low quantity (cluster I) and good quality motivation group (cluster II) on handling the instrument Spektra^{TM}, carrying out the experiments and safety are displayed in Table 10, while the results of statistical significance of t-test are shown in Table 11.

Table 10
Descriptive Statistics – students' opinions about handling the instrument, materials and safety

Students' opinions	Cluster Number of Case	N	M	SD
Spektra^{TM} is easy to handle.	1	144	3.67	1.18
	2	119	4.17	1.04
Step-on approach easy to follow.	1	144	3.60	1.03
	2	119	3.87	1.00
Selected experiments are interesting.	1	143	3.59	.97
	2	119	3.92	1.11
Handling reagent bottles with droppers was easy.	1	143	3.76	1.08
	2	119	3.97	1.16
Important that commercial instruments are not used.	1	143	2.99	1.23
	2	118	2.55	1.39
Experiments were safe.	1	144	3.61	1.10
	2	119	3.72	1.28

Table 11
Differences in the students' opinions on handling the instruments, materials and safety (t-test)

Students' opinions	t	df	Sig. (2-tailed)
Spektra ^{TM} is easy to handle	-3.57	261	.000
Step-on approach easy to follow	-2.14	261	.033
Selected experiments are interesting	-2.57	260	.011
Handling reagent bottles with droppers was easy	-1.52	260	.129
Important that commercial instruments are not used	2.73	259	.007
Experiments were safe	-0.76	261	.446

IV.2.3 Differences between participating schools and study programs

Apart from the impact of motivational orientations on students' academic achievements and attitudes towards the hands-on approach to visible spectrometry, the aim of the study was also to assess the impact of different schools and their study programs on knowledge gained and students' attitudes. Results are displayed in Tables 12 to 19.

Table 12
Descriptive Statistics – participating institutions in pre-test, post-test, and prior academic achievements by academic achievements

		N	M	SD
Pre-test	BIC_T_2010	45	75.97	16.59
	BIC_gim	19	57.67	24.63
	Chem_T	36	74.88	10.86
	BIC_T_2009	30	71.45	10.26
	Poland_T	92	69.19	16.51
	PIRAMIDA_T	28	48.45	16.64
	PHAR_T	27	52.82	26.19
	BC Naklo	18	59.03	13.76
	Total	295	66.32	19.18
Post-test	BIC_T_2010	45	72.75	11.37
	BIC_gim	19	73.19	16.49
	Chem_T	36	80.90	12.53
	BIC_T_2009	30	53.95	12.07
	Poland_T	92	53.84	26.06
	PIRAMIDA_T	28	57.26	17.25
	PHAR_T	27	70.63	16.01
	BC Naklo	18	69.51	10.85
	Total	295	64.10	21.00
Prior academic achievement	BIC_T_2010	45	3.53	0.79
	BIC_gim	19	2.89	0.88
	Chem_T	36	3.61	0.77
	BIC_T_2009	0	.	.
	Poland_T	0	.	.
	PIRAMIDA_T	27	4.07	0.68
	PHAR_T	26	3.42	0.76
	BC Naklo	0	.	.
	Total	153	3.55	0.83

Legend: BIC_T_2010 – Secondary Education Centre, Ljubljana, class 2010; BIC_T_2009 –Secondary Education Centre, Ljubljana, class 2009; BIC_gim – Secondary Education Centre, Ljubljana, general program; Chem_T – Technical Chemistry School, Ljubljana; Poland_T – Technical High School, Poland; PIRAMIDA_T – Educational Centre Piramida, Maribor; PHAR-T Secondary School for Pharmacy, Cosmetics and Health Care, Ljubljana; BC Naklo – Biotechnical Centre Naklo, For Poland_T, BC Naklo and BIC_T_2009 data on prior academic achievements in chemistry related subjects were not available.

Table 13
Differences in the students' prior academic achivements, by participating institutions and achievements on pre- and post-test (ANOVA)

		Sum of Squares	df	Mean Square	F	Sig.
Pre-test	Between Groups	24622.39	7	3517.48	12.08	.000
	Within Groups	83539.87	287	291.08		
	Total	108162.26	294			
Post-test	Between Groups	30865.72	7	4409.39	12.81	.000
	Within Groups	98780.57	287	344.18		
	Total	129646.30	294			
Academic achievement 2	Between Groups	16.14	4	4.03	6.81	.000
	Within Groups	87.74	148	0.59		
	Total	103.88	152			

Statistically significant differences on the α-level of 1% between schools and programmes were detected for students' prior achievements (grades in chemistry related subjects) as well as for mean score values on pre- and post-test (see Table 12 and 13).

Differences between schools were also found in students' opinions on didactical aspects of the worked modules (see Table 14 and 15).

Table 14
Descriptive Statistics – differences between schools in students' opinions about different didactical aspects of the worked modules on spectrometry

Didactical aspect of modules		N	M	SD
Usefulness of student's workbook	BIC_T_2010	45	3.93	1.07
	BIC_gim	19	3.32	.95
	Chem_T	36	3.19	1.14
	Poland_T	92	3.01	1.23
	PIRAMIDA_T	28	3.00	.77
	PHAR_T	25	3.36	.99
	BC Naklo	18	2.83	1.25
	Total	263	3.24	1.15
Teacher's support	BIC_T_2010	45	3.02	1.06
	BIC_gim	19	1.84	.90
	Chem_T	36	3.47	1.11
	Poland_T	92	2.45	1.34
	PIRAMIDA_T	28	2.96	.74
	PHAR_T	25	3.84	1.11
	BC Naklo	18	3.33	1.37
	Total	263	2.89	1.27
Group work	BIC_T_2010	45	3.98	.97
	BIC_gim	19	4.00	.67
	Chem_T	36	3.97	1.08
	Poland_T	92	3.88	1.06
	PIRAMIDA_T	28	3.54	1.04

	PHAR_T	25	2.88	1.45
	BC Naklo	18	3.44	1.25
	Total	263	3.76	1.12
Relaxing climate	BIC_T_2010	45	4.20	0.97
	BIC_gim	19	4.16	0.96
	Chem_T	36	4.36	0.72
	Poland_T	92	3.55	1.14
	PIRAMIDA_T	28	3.43	1.10
	PHAR_T	25	3.32	1.03
	BC Naklo	18	3.50	1.34
	Total	263	3.78	1.11
Impact on concepts' understanding	BIC_T_2010	44	3.48	1.13
	BIC_gim	19	3.32	1.06
	Chem_T	36	3.64	1.05
	Poland_T	92	3.14	1.00
	PIRAMIDA_T	27	3.26	.86
	PHAR_T	24	3.71	.95
	BC Naklo	18	3.22	1.26
	Total	260	3.35	1.05
Hands-on approach	BIC_T_2010	44	4.34	.91
	BIC_gim	19	3.95	.97
	Chem_T	36	4.44	.77
	Poland_T	92	3.74	.91
	PIRAMIDA_T	28	3.46	1.04
	PHAR_T	25	3.32	1.18
	BC Naklo	18	3.56	1.25
	Total	262	3.87	1.03

Legend: BIC_T_2010 – Secondary Education Centre, Ljubljana, class 2010; BIC_gim – Secondary Education Centre, Ljubljana, general program; Chem_T – Technical Chemistry School, Ljubljana; Poland_T – Technical High School, Poland; PIRAMIDA_T – Educational Centre Piramida, Maribor; PHAR-T Secondary School for Pharmacy, Cosmetics and Health Care, Ljubljana; BC Naklo – Biotechnical Centre Naklo

Table 15
Differences between schools in didactical aspects of the worked modules (ANOVA)

Didactic aspects of worked modules		Sum of Squares	df	Mean Square	F	Sig.
Usefulness of student's workbook	Between Groups	31.59	6	5.27	4.27	.000
	Within Groups	315.79	256	1.23		
	Total	347.38	262			
Teacher's support	Between Groups	78.27	6	13.05	9.67	.000
	Within Groups	345.53	256	1.35		
	Total	423.80	262			
Group work	Between Groups	28.74	6	4.79	4.12	.001
	Within Groups	297.68	256	1.16		
	Total	326.43	262			
Relaxing climate	Between Groups	37.65	6	6.28	5.67	.000
	Within Groups	283.56	256	1.11		
	Total	321.21	262			
Hands-on approach	Between Groups	37.28	6	6.21	6.65	.000
	Within Groups	238.31	255	0.93		
	Total	275.59	261			

Further, statistically significant differences between schools were found in students' opinion on knowledge and skills gained through the hands-on approach towards visible spectrometry (see Tables 16 and 17).

Table 16
Descriptive Statistics - differences between schools in students' opinions on knowledge and skills gained through the hands-on approach

		N	M	SD
Colour of matter and absorption of light	BIC_T_2010	45	3.22	1.17
	BIC_gim	19	3.11	1.20
	Chem_T	36	3.75	1.13
	Poland_T	92	3.07	1.05
	PIRAMIDA_T	28	2.86	.85
	PHAR_T	25	3.92	1.22
	BC Naklo	18	3.06	1.16
	Total	263	3.25	1.13
LED selection	BIC_T_2010	45	3.27	1.14
	BIC_gim	19	3.47	1.12
	Chem_T	36	4.28	.81
	Poland_T	92	3.29	1.02
	PIRAMIDA_T	28	3.29	1.08
	PHAR_T	25	5.76	8.03
	BC Naklo	18	3.33	1.28

	Total	263	3.67	2.73
Role of the blank	BIC_T_2010	45	3.58	1.06
	BIC_gim	19	3.53	1.26
	Chem_T	36	4.31	0.79
	Poland_T	92	3.45	1.11
	PIRAMIDA_T	28	3.18	1.02
	PHAR_T	25	4.20	1.08
	BC Naklo	18	3.67	1.37
	Total	263	3.65	1.13
Handling the instrument Spektra^{TM}	BIC_T_2010	45	3.89	1.03
	BIC_gim	19	3.42	.96
	Chem_T	36	4.53	.81
	Poland_T	92	3.43	1.07
	PIRAMIDA_T	27	3.19	1.14
	PHAR_T	25	4.12	.88
	BC Naklo	18	3.50	1.47
	Total	262	3.71	1.12
T/A relation	BIC_T_2010	45	3.31	1.08
	BIC_gim	19	3.42	1.17
	Chem_T	36	4.06	.98
	Poland_T	92	3.21	1.07
	PIRAMIDA_T	28	2.86	.89
	PHAR_T	25	4.08	.86
	BC Naklo	18	3.17	1.10
	Total	263	3.40	1.10
Self confidence	BIC_T_2010	45	3.42	1.14
	BIC_gim	19	3.05	1.35
	Chem_T	36	3.33	1.20
	Poland_T	92	3.41	1.00
	PIRAMIDA_T	28	2.71	.81
	PHAR_T	24	3.79	.93
	BC Naklo	18	2.72	1.36
	Total	262	3.29	1.11
Use of spectrometry in determination of concentration	BIC_T_2010	45	3.73	.94
	BIC_gim	19	3.58	.84
	Chem_T	36	4.11	.98
	Poland_T	92	3.27	1.05
	PIRAMIDA_T	27	3.19	.74
	PHAR_T	25	4.00	1.08
	BC Naklo	18	3.39	1.20
	Total	262	3.56	1.04

Legend: BIC_T_2010 – Secondary Education Centre, Ljubljana, class 2010; BIC_gim – Secondary Education Centre, Ljubljana, general program; Chem_T – Technical Chemistry School, Ljubljana; Poland_T – Technical High School, Poland; PIRAMIDA_T – Educational Centre Piramida, Maribor; PHAR-T Secondary School for Pharmacy, Cosmetics and Health Care, Ljubljana; BC Naklo – Biotechnical Centre Naklo

Table 17
Differences between schools in knowledge and skills gained through the hands-on approach (ANOVA)

		Sum of Squares	df	Mean Square	F	Sig.
Colour of matter and absorption of light	Between Groups	28.79	6	4.80	3.99	.001
	Within Groups	308.14	256	1.20		
	Total	336.94	262			
LED selection	Between Groups	149.77	6	24.96	3.54	.002
	Within Groups	1804.11	256	7.05		
	Total	1953.88	262			
Role of the blank	Between Groups	33.63	6	5.60	4.78	.000
	Within Groups	300.19	256	1.17		
	Total	333.82	262			
Handling the instrument Spektra^{TM}	Between Groups	46.50	6	7.75	7.06	.000
	Within Groups	279.87	255	1.10		
	Total	326.37	261			
T/ A relation	Between Groups	40.07	6	6.68	6.22	.000
	Within Groups	275.00	256	1.07		
	Total	315.08	262			
Self confidence	Between Groups	24.44	6	4.07	3.47	.003
	Within Groups	299.51	255	1.17		
	Total	323.95	261			
Use of spectrometry for determination of concentration	Between Groups	29.09	6	4.85	4.92	.000
	Within Groups	251.55	255	0.99		
	Total	280.64	261			

Statistically significant differences between schools on the α-level of 1% or 5% were also found for students' opinions on handling the instruments and materials while carrying out experiments and safety aspects of the selected experiments (see Tables 18 and 19).

Table 18
Descriptive Statistics - differences between schools ion students' opinions about handling the instrument, materials and safety

Opinion about handling the instrument, materials and safety		N	M	SD
SpektraTM is easy to handle	BIC_T_2010	45	4.00	1.07
	BIC_gim	19	4.16	.83
	Chem_T	36	4.50	.74
	Poland_T	92	3.68	1.23
	PIRAMIDA_T	28	3.32	1.12
	PHAR_T	25	4.28	1.06
	BC Naklo	18	3.61	1.29
	Total	263	3.90	1.14
Easy to follow step-by-step description of the experimental procedures	BIC_T_2010	45	3.93	1.01
	BIC_gim	19	3.53	.84
	Chem_T	36	4.11	.89
	Poland_T	92	3.57	.99
	PIRAMIDA_T	28	3.36	1.06
	PHAR_T	25	4.20	.82
	BC Naklo	18	3.39	1.38
	Total	263	3.73	1.02
Handling reagent bottles with droppers was easy	BIC_T_2010	45	3.64	1.38
	BIC_gim	18	3.56	1.20
	Chem_T	36	3.97	1.11
	Poland_T	92	4.03	.92
	PIRAMIDA_T	28	3.46	.92
	PHAR_T	25	4.28	1.06
	BC Naklo	18	3.50	1.34
	Total	262	3.85	1.12
Important that commercial instruments are not used	BIC_T_2010	43	3.42	1.24
	BIC_gim	19	2.05	.97
	Chem_T	36	2.25	1.36
	Poland_T	92	3.02	1.26
	PIRAMIDA_T	28	2.68	.86
	PHAR_T	25	2.56	1.69
	BC Naklo	18	2.50	1.29
	Total	261	2.79	1.32
Experiments were safe	BIC_T_2010	45	3.73	1.36
	BIC_gim	19	3.11	1.33
	Chem_T	36	3.58	1.42
	Poland_T	92	3.80	.95
	PIRAMIDA_T	28	3.14	1.01
	PHAR_T	25	4.32	.80
	BC Naklo	18	3.39	1.29
	Total	263	3.66	1.18

Legend: BIC_T_2010 – Secondary Education Centre, Ljubljana, class 2010; BIC_gim – Secondary Education Centre, Ljubljana, general program; Chem_T – Technical Chemistry School, Ljubljana; Poland_T – Technical High School, Poland; PIRAMIDA_T – Educational Centre Piramida, Maribor; PHAR-T Secondary School for Pharmacy, Cosmetics and Health Care, Ljubljana; BC Naklo – Biotechnical Centre Naklo

Table 19
Differences between schools in handling the instruments, materials and safety (ANOVA)

Opinion about handling the instrument, materials and safety		Sum of Squares	df	Mean Square	F	Sig.
SpektraTM is easy to handle	Between Groups	33.42	6	5.57	4.62	.000
	Within Groups	308.81	256	1.21		
	Total	342.23	262			
Step-on approach is easy to follow	Between Groups	21.88	6	3.65	3.70	.002
	Within Groups	252.41	256	0.99		
	Total	274.29	262			
Selected experiments are interesting	Between Groups	34.09	6	5.68	5.75	.000
	Within Groups	251.77	255	0.99		
	Total	285.87	261			
Important that commercial instruments Are not used	Between Groups	45.94	6	7.66	4.78	.000
	Within Groups	406.89	254	1.60		
	Total	452.83	260			
Experiments were safe	Between Groups	27.92	6	4.65	3.54	.002
	Within Groups	336.96	256	1.32		
	Total	364.88	262			

We were also interested in gender differences. The results show that only for post-test results a statistically significant difference at the α -level of 1% was found (see Tables 20 and 21). But at the α -level of 5 % differences are observed also for intrinsic and controlled motivation as well as for prior academic achievements in chemistry related subjects.

Table 20
Descriptive Statistics – Gender differences

Parameters	Gender	N	M	SD
Pre test	M	104	65.11	18.72
	F	147	64.51	19.55
Post test	M	104	67.67	20.77
	F	147	58.61	21.94
Academic achievement	M	54	3.39	0.83
	F	54	3.72	0.83
Controlled_M	M	104	2.86	0.57
	F	147	3.04	0.62
Intrinsic_M	M	104	3.01	0.98
	F	147	2.75	0.95
Regulated_M	M	104	3.29	0.75
	F	147	3.30	0.77
Self_determination	M	104	3.23	0.92
	F	147	2.92	1.00

Table 21
Gender differences (t-test)

Parameters	t	df	Sig. (2-tailed)
Pre test	.244	249	.807
Post test	3.292	249	.001
Academic achievement	-2.078	106	.040
Controlled_M	-2.320	249	.021
Intrinsic_M	2.125	249	.035
Regulated_M	-.033	249	.974
Self_determination	2.519	249	.012

IV.2.4 Impact of the hands-on approach on specific knowledge from visible spectrometry

In order to identify the impact of the hands-on approach on learning concepts from visible spectrometry, a pre-test (10 short test items) and post-test (21 short items) were designed and semi-standardized. The conceptual structure of the pre-test and mean values of scores achieved at each test item is shown in Table 22, and the conceptual structure of the post-test in Table 23.

Table 21
Concepts included in the pre-test and mean values of scores achieved

Test item	Concepts and their relation	N	Min.	Max.	M	SD
Item_1_a	Conditions for colour perception	301	.00	.50	.19	.11
Item_1_b	Conditions for colour perception	301	.00	.50	.20	.10
Item_1_c	Conditions for colour perception	301	.00	.75	.38	.22
Item_2_a	**Additive mixing red and blue light**	301	.00	.50	.35	.23
Item_2_b	**Additive mixing red and green light.**	299	.00	.50	.15	.23
Item_3_a	Effect of dilution of coloured solution on concentration.	301	.00	.50	.44	.16
Item_3_b	Effect of dilution of coloured solution on colour intensity.	300	.00	.50	.38	0.21
Item_4_1_c	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation - horizontally	301	.00	.50	.34	.23
Item_4_1_d	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation - horizontally	301	.00	.50	.34	.23
Item_4_1_e	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation - horizontally	301	.00	.50	.35	.23
Item_4_2_f	**Effect of dilution of coloured solution on colour intensity in relation to the direction of observation - vertically**	301	.00	.50	.40	.20
Item_4_2_g	**Effect of dilution of coloured solution on colour intensity in relation to the direction of observation - vertically**	301	.00	.50	.09	.19

Total scores		302	.00	5.75	3.60	1.15

Note: Test items which are bold were included in pre- and post-test in order to detect the contribution of the hands-on approach to the better understanding of concepts from visible spectrometry.

Table 23
Concepts included in the post-test and mean values of scores achieved

Test item	**Concepts and their relations**	N	Min.	Max.	M	S D
Item_1	Wavelength of light and colour.	302	.00	1.00	0.55	0.50
Item_2_a	LED selection - colour of absorption medium.	302	.00	.50	0.33	0.25
Item_2_b	Reason for LED selection	302	.00	.50	0.28	0.26
Item_3_a	Deduction of colour of a filter foil from its transmittance (*T*) graph for red, green and blue LED.	302	.00	.50	0.27	0.26
Item_3_b	Selection of LED with the highest absorbance.	302	.00	.50	0.28	0.25
Item_4_a	Correlation of *T* / and number of layers of a filter foil.	302	.00	.25	0.18	0.11
Item_4_b	Using the graph *T*/ and number of layers for determination of transmittance	302	.00	.25	0.22	0.08
Item_4_c	Functional relation between *T*/and number of filter foils.	302	.00	.25	0.21	0.10
Item_4_d	Functional relation between *T*/and number of filter foils.	302	.00	.25	0.19	0.11
Item_4_e	Functional relation between *T*/and number of filter foils.	302	.00	.25	.21	.10
Item_5	Transmittance/Absorbance and concentration of the absorption medium correlation.	302	.00	1.00	.44	.50
Item_6	Equation of the Lamber-Beer Law.	302	.00	1.00	.85	.35
Item_7	Selection of the blank.	302	.00	1.00	.63	.48
Item_8_a	Determination of concentration from the calibration line.	302	.00	.50	.41	.19
Item_8_b	Limitations in the use of a displayed calibration line in relation with the concentration of the absorption media.	302	.00	.50	.25	.24
Item_8_c	Limitations in the use of a displayed calibration line in relation with the concentration of the absorption media.	302	.00	.50	.23	.24
Item_9_a	**Additive mixing of red and blue light.**	302	.00	.50	.43	.18
Item_9_b	**Additive mixing of red and green light.**	302	.00	.50	.36	.23
Item_10_a	**Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – vertically.**	302	.00	.50	.42	.18
Item_10_b	**Effect of dilution of coloured solution on colour intensity in relation to the direction of observation - vertically.**	302	.00	.50	.20	0.25
Total scores		302	.50	10.75	6.95	2.33

Note: Test items which are bold were included in pre- and post-test in order to detect the contribution of the hands-on approach to the better understanding of concepts from visible spectrometry.

Mean values of total scores achieved at the pre- and post-test, and scores achieved on the same test items at pre-test and post-test are displayed in Table 24.

Table 24
Total scores achieved at pre- and post-test, and scores achieved at the same test items on pre- and post-test

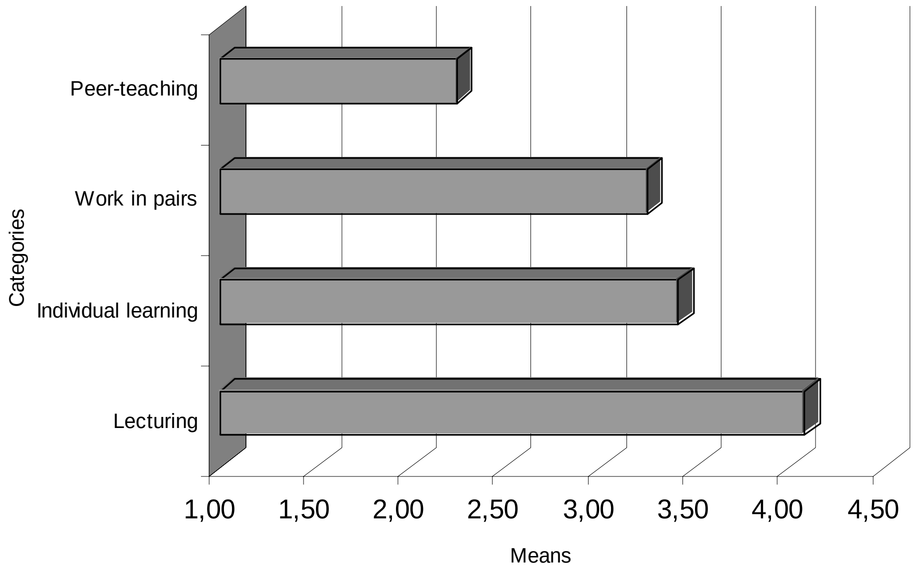
	Total_scores_pre	Total_scores_post	Same_items_pre	Same_items_post
N	302	302	302	302
M	64,65	62,68	46,58	70,04
SD	21.64	20.06	24.88	27.87
Min.	4.65	.00	.00	.00
Max.	100.00	100.00	100.00	100.00

Table 25
Total scores achieved at pre- and post-test and scores achieved on the same test items at pre- and post-test (paired samples test)

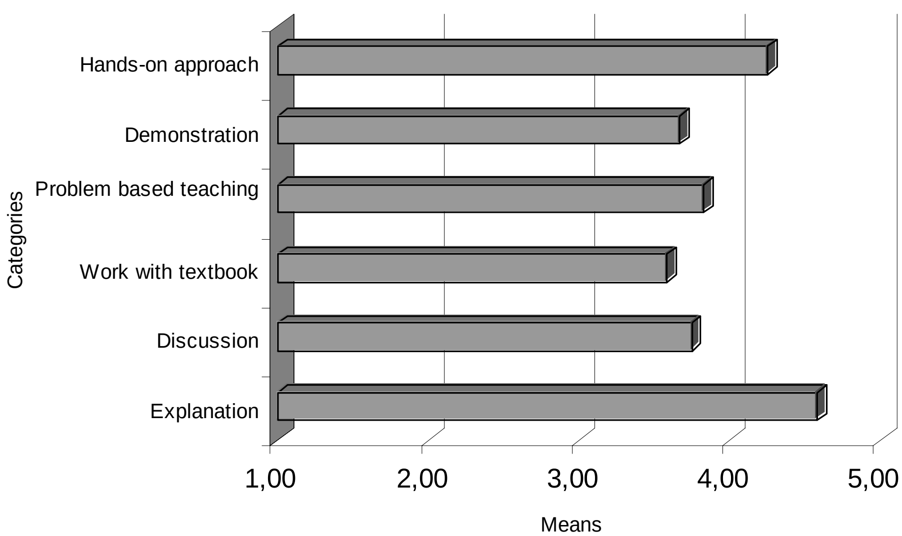
		t	df	Sig. (2-tailed)
Pair 1	Total_scores_pre-test Total_scores_post-test	1,593	301	,112
Pair 2	Same_items_pre-test Same_items_post-test	-13,729	301	,000

IV.2.5 Hands-on approach to visible spectrometry from teachers' view point

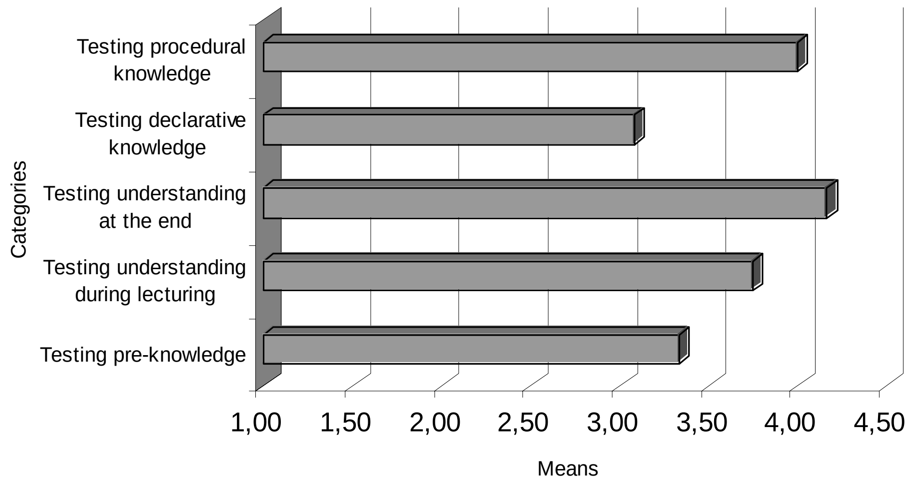
Teachers' opinions, recommendations and suggestions for the improvement of the hands-on approach to visible spectrometry for vocational schools were collected by a specially designed questionnaire. The questionnaire had both a general and a specific part related to the study modules from visible spectrometry. In the general part teachers had to indicate on the 5-point scale from 5 (always) to 1 (never) how often they use in the classroom different teaching strategies, methods, and students' knowledge assessment. In the specific part they were asked to express their opinions on the acceptability of study modules from the view point of their impact on learning concepts, didactic approach, their usefulness, and preparation for classroom work. Four teachers from Slovenia and 8 teachers from Poland responded; 2 males and 10 females. Their average working period was 14.5 years. The results of the analysis of the general part of the questionnaire are displayed in Graphs 1 to 3.



Graph 1
The teaching strategies most often used in classrooms

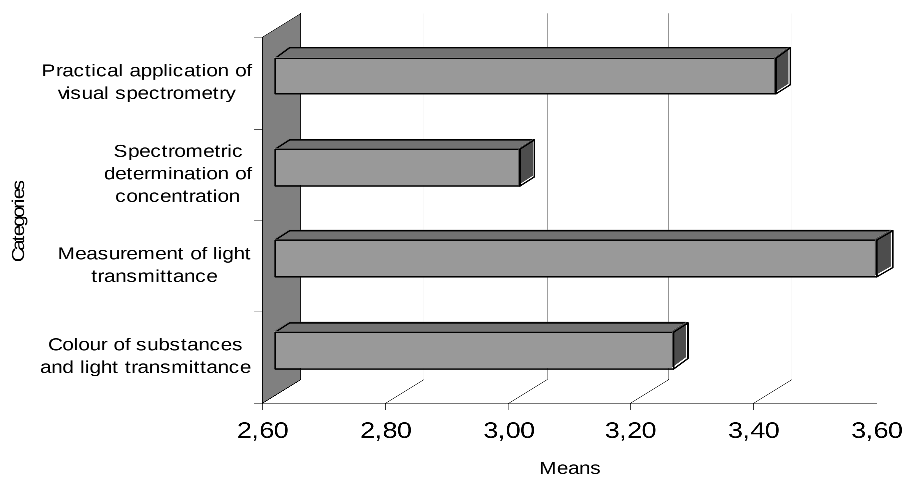


Graph 2
The most often used teaching methods

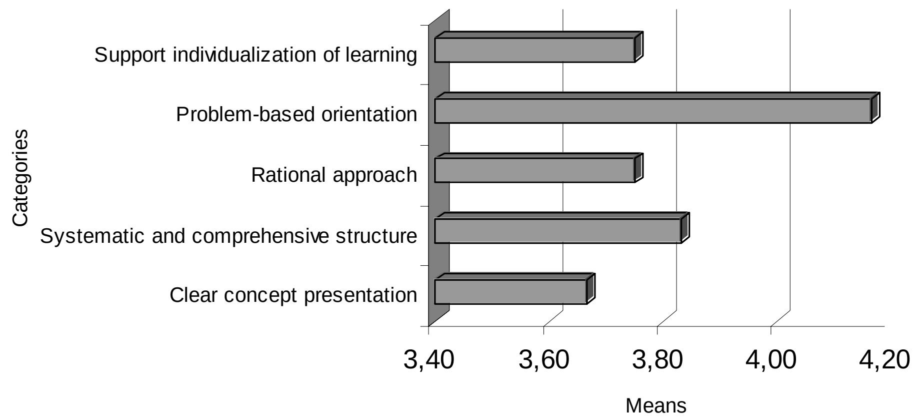


Graph 3
The most often used forms of testing student's knowledge

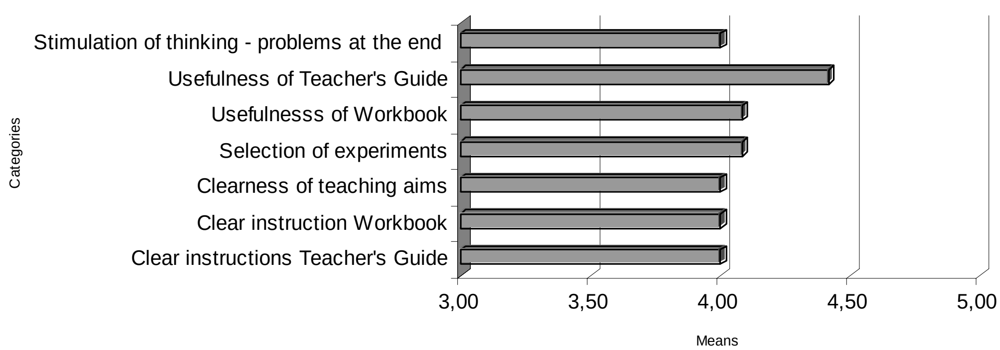
The results of the analysis of the specific part of the questionnaire are displayed in Graphs 4 to 7.



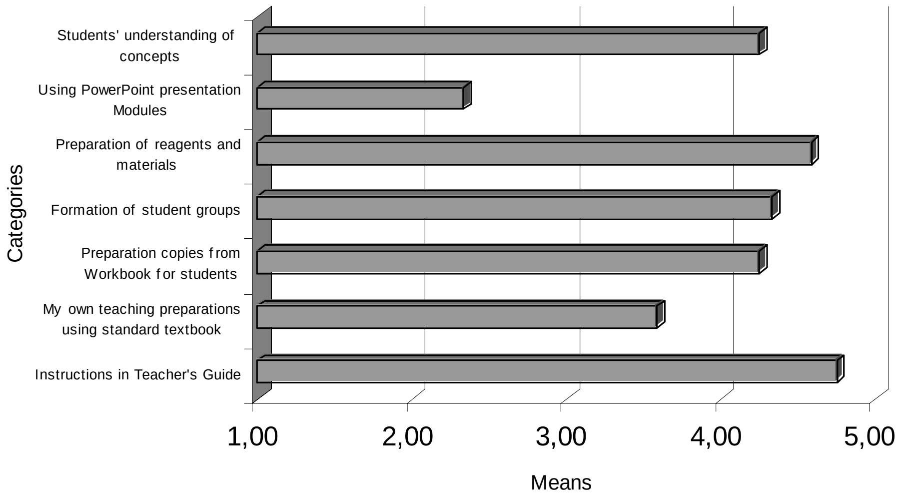
Graph 4
The impact of modules on learning



Graph 5
Evaluation of the didactic approach



Graph 6
Evaluation of different components of the modules



Graph 7
The importance of different elements in preparing and conducting the hands-on procedure

IV.2.6 Results from Bristol high schools

Due to missing data on pre-test, post-test and the only partially filled in motivation and attitudes questionnaire, only motivational orientations of respondents from the UK were identified by the *k*-means clustering procedure (see Table 26).

Table 26: Motivational orientations of high school students from Bristol

Dimension	Cluster I	Cluster II
Intrinsic motivation	2.65	3.77
Regulated motivation	3.18	4.09
Controlled motivation	2.82	3.17
Self-concept	2.11	3.77
No. of cases in each cluster	21	83

Based on the values of autonomous motivation (i.e., $M_{intrinsic} = 2.65$, and $M_{regulated} = 3.18$) and controlled motivation (M = 2.82), cases in cluster I could be identified as a low quantity motivation group, while members of cluster II as a high quantity motivation group (high autonomous and high or above average controlled motivation). It is important to stress , that only 21 students belong to cluster I, and 83 students to cluster II. This result could be justified by the nature of the students: since they are engaged in outreach activities in chemistry, organized by the University of Bristol, they ought to be already interested in chemistry and science subjects in general.

V Discussion

V.1 Answers to study questions

V.1.1 Students' motivational orientations

Among the student population included in the study, two distinct motivational orientations (i.e. profiles) were identified by the *k*-2 nearest clustering procedure: (1) cluster I – a low quantity motivation group and cluster II – a good quality motivation group (Table 3). The distribution of cases between classes shows that 55% of the participating students belong to cluster I and 45% to cluster II. However, taking into account that students who took part in the study are coming primarily from vocational and technical schools, the obtained distribution is in accordance with our expectations. In the study by Vrtačnik, Juriševič and Ferk (2010) in which students from Slovenian grammar schools took part, 48% of the student population was classified as a low quantity motivation group and 52% as a good quality motivation group, but these students came from schools in which the program is designed to provide students with good background knowledge from science, mathematics, languages, and humanities for further studies at the university level.

V.1.2 The impact of motivational orientation on academic achievements

For identification of the differences between two motivational orientations in academic achievements on pre-test, post-test and prior achievements in chemistry related subjects an independent sample t-test was performed, using as grouping variable the *k*-2 classification of cases (Tables 4 and 5). On the pre-test, results of the low quantity motivation group of students were levelled with the good quality motivation group; no statically significant difference was determined, but on the post-test results, the difference in academic achievements between the two groups was found to be statistically significant at the α-level of 1%. The mean value of scores achieved by the good quality motivation group of students was 69.63%, while for the low quantity motivation group only 59.63% (Table 4). The differences in academic achievements between the two motivational orientations of students is also detected for their prior-knowledge in chemistry based subjects; the mean grade value of the good quality motivation group is at the α-level of 5% and is higher ($M = 3.75$ on the 5-point scale) than the average result of the low quantity motivation group of students ($M = 3.32$) (Tables 4 and 5). These results are in line with other studies in which a positive correlation between autonomous motivation and good academic achievements was identified (Boiche, Sarrazin, Grouzet, Pelletier, & Chanal, 2008; Deci, & Ryan, 2008). We could conclude that the hands-on approach as experienced by the students during working with modules from visible spectrometry offered primarily students with high autonomous motivation (Cluster II) the freedom to explore and search for explanations of the experimental results on their own, without constant guidance by the teacher, so the working climate experienced by the approach stimulated their learning process.

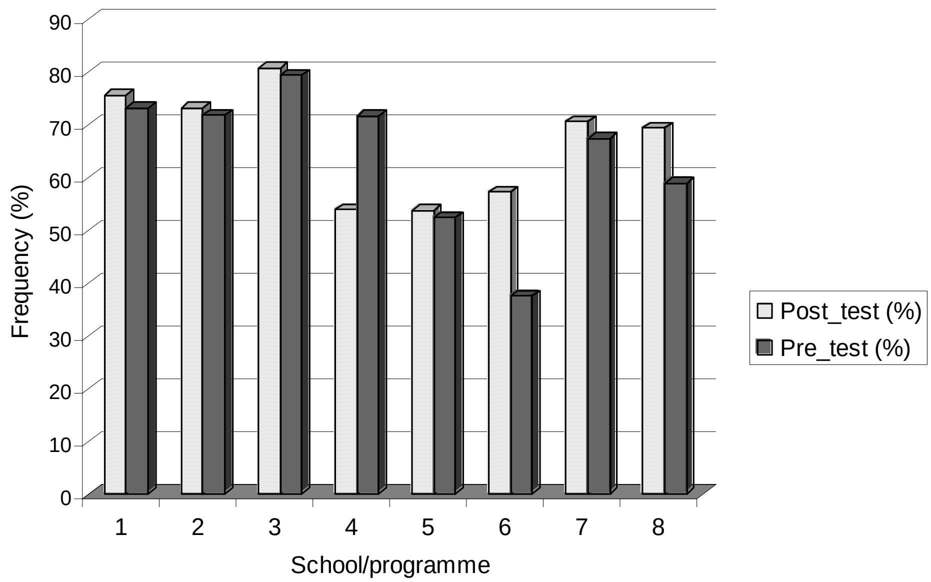
V. 1.3 The impact of motivational orientation on students' opinions and attitudes toward the didactical aspect of worked modules from visible spectrometry, better mastering of specific knowledge and skills in handling the instruments and materials

Students classified as the good quality motivation group (Cluster II), appreciate more the help of the Workbook in carrying out the experiments, the teacher's guidance of the experimental work, the relaxing yet working climate that prevailed during the work, the impact of the approach on their knowledge from visible spectrometry, and the hands-on approach they were exposed to, than did students from the low quantity motivation group (Cluster I). Differences in the mean values of points assigned to the selected elements of the didactic approach are statistically significant at the α-level of 1% or 5%, respectively (Tables 6 and 7). The good quality motivation group of students further stated that the approach enabled them to master better the specific knowledge and skills from visible spectrometry (i. e. the relation of

colour of matter and light absorption, selection of the appropriate LED for measurement of transmittance, the role of the blank in the measurements, the relation of transmittance and absorbance and the usage of spectrometry for the determination of concentration, handling the instruments and materials). Differences in the mean values of points assigned to the specific knowledge and skills gained are statically significant at the α-level of 1% or 5%, respectively (Tables 8 and 9). This result is confirmed also by the differences between the two motivation groups of students in scores achieved at the post-test (see Table 4). Students' opinions on the safety aspects of the selected experiments, easiness to follow the step-wise experimental procedures, and handling reagent bottles with droppers are weighted equally by both groups of students. The statistically significant difference on the level of significance 0.01 was found only for the evaluation of handling the instrument Spektra™; the good quality motivation group found handling with the instrument easier than did the low quantity motivation group, however the low quantity motivation group appreciated less the fact that instead of a commercial instrument for the measurements, the didactically more appropriate Spektar™ was used (Tables 10 and 11).
These results are in accordance with the findings of Moore (2006), that hands-on laboratory work enables the achievements of a series of learning goals, among them subject-matter mastery and better reasoning. The research of O'Neill and Polman (2004) also revealed that student-centred science activities contribute to better academic achievements, since they improve scientific literacy. The reason that the good quality motivation group of students profited more than the low quantity motivation group is that student-centred activities support autonomous learning, which suits better to the students with higher autonomous motivation (Chirkov, & Ryan, 2001; Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004).

V.1.4 Impact of the vocational school study program on students' achievement on the pre- and post-test

In the study, five vocational high schools from Slovenia with different study programs: (a) biotechnology, (b) food processing,(c) pharmacy, cosmetics and health care, (d) chemistry technician, and (e) grammar school – general, and 7 technical high schools from Poland took part. Therefore we were interested in the impact of the study program on the students' achievements on the pre- and post-test. The results are displayed in Tables 12 and 13. Statistically significant differences in students' academic achievement at the α-level of 1% between study programmes were found by one-way ANOVA. From Graph 8 it can be seen that the best results on the pre-test and on the post-test were achieved by students enrolled in the program chemistry technician, while students from BIC – biotechnology, class 2010 and general program achieved similarly good results on the pre- as well as the post-test. Unexpected are the results of students from the BIC – biotechnology program, class 2009, whose pre-test results were much better than the post-test results. Their pre-knowledge was at the equal level as that of the students from the same program, but class 2010, however the knowledge gainded through the hands-on approach was at much lower level (see Graph 8). It is possible to deduce that their approach towards hands-on modules from visible spectrometry was not serious enough to influence their improvement in knowledge.



Legend: 1. BIC - Biotechnology, class 2010, 2. BIC - General program, 3. Chemical technician, 4. BIC - Biotechnology, class 2009, 5. Polish technical schools, 6. Food processing , Piramida, 7. Technical school for pharmacy, cosmetics and health care, 8. BC Biotechnology, Naklo

Graph 8
Impact of the study program on students' academic achievements

In spite of the fact that students from the food processing program (school 6) achieved the lowest results on pre- and post-tests, their knowledge gained through the hands-on approach is the greatest.
Results revealed that the study program contributes to the academic achievements of students. Students enrolled in the chemistry technician program have, according to expectations, a much more solid background knowledge of chemistry than students from other vocational and technical school programs.

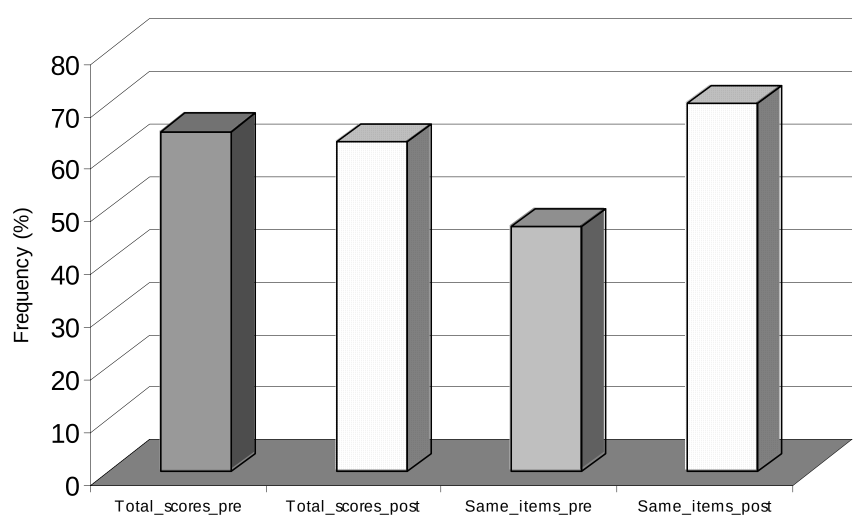
V.1.5 Impact of the study program on students’ opinion and attitude toward the didactical aspect of worked modules from visible spectrometry, better mastering of specific knowledge and skills in handling the instruments and materials

Students’ study programs are also reflected in differences in student opinions and attitudes towards the didactical aspects of the worked modules. Statistically important differences in the level of significance 0.01 or 0.05 were revealed for evaluating: (1) the usefulness of student’s workbook, (the highest average score by BIC- biotechnology, class 2010), (2) teacher’s guidance of experimental work (the highest average score by the Chemical technician program), (3) the possibility to work in groups (the highest average score by BIC – general program), (4) relaxing climate (the highest average score by the Chemical technician program), (5) and the hands-on approach (the highest average score by the Chemical technician program), Tables 14 and 15. Students from study programs in which the hands-on approach is more often practised during the laboratory work evaluated didactical aspects of the worked modules higher than did students who are not used to this approach. When evaluating the improvement in mastering of specific knowledge gained through the hands-on approach to visible spectrometry, the highest average scores were assigned to all knowledge segments (understanding the relation of colour of matter and light absorption, selection of LED for measurement of transmittance, the role of the blank in transmittance measurements, handling the instrument Spektra^{TM}, understanding the relation between transmittance and absorbance, the use of spectrometry in determination of concentration) by students enrolled in the chemistry technician program. These results are in line with their high achievements at pre-test (74.88%) and post-test

(80.90%), respectively. Differences between schools in evaluating the improvement in mastering specific knowledge through the hands-on approach are statistically important at the α-level of 1% or 5%, respectively (Tables 16 and 17).
Further, differences between schools in student's opinion were also found for handling the instrument, materials and safety: (1) easy work with Spektra™ (the highest average score by the Chemical technician program, (2) easy to follow step-by-step description of the experimental procedures (the highest average score by the Technical school for pharmacy, cosmetics and health care), (3) selected experiments are interesting (the highest average score by the Chemical technician programme), (4) importance that a commercial instrument was not used (the highest average score by BIC – biotechnology, class 2010), and (5) experiments are safe (the highest average score by the Technical school for pharmacy, cosmetics and health care). Differences are statically important at the α-level of 1% or 5%, respectively (Tables 18 and 19).

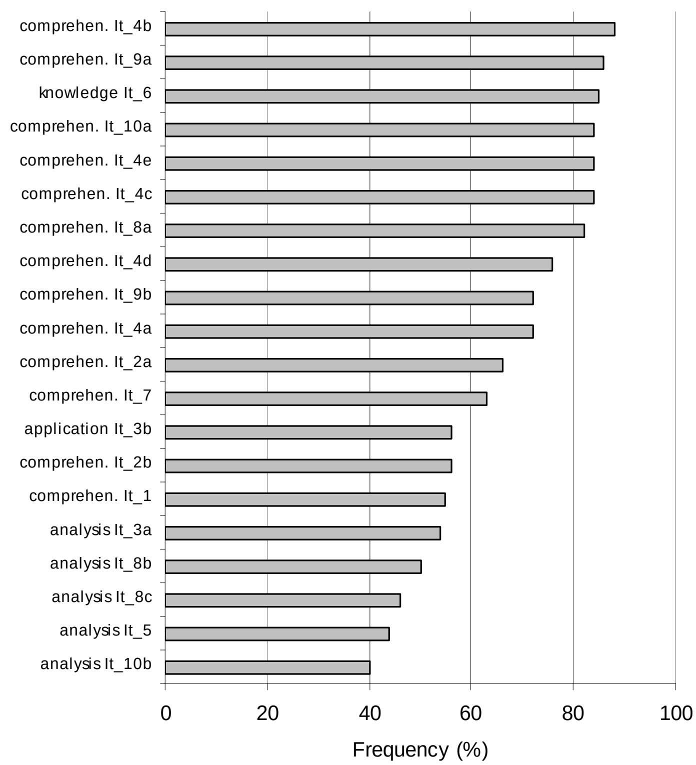
V.1.6 Impact of the hands-on approach to visible spectrometry on the quality of knowledge gained

The following basic concepts were included in the pre-test: conditions for colour perception, additive mixing of coloured beams of light, effect of dilution of coloured solution on concentration and colour intensity in relation with the direction of observation of coloured samples and volume of sample. Our assumption was that the majority of the concepts should be known to the students either from their experiences or previous experimental work. The selection of concepts included in post-tests was based on the knowledge structure of the four modules selected from the hands-on approach to visible spectrometry. We were specifically interested in students' understanding of the following concepts: transmittance in relation to concentration of samples, length of light path through sample, relation of transmittance with absorbance, the usage of a calibration line for determination of concentration, the composition of the blank in relation with the composition of the sample, and selection of the light emitter LED in relation to the colour of the sample. Four test items in the pre-test and post-test were the same. The detailed structure of the pre-test and post-test, and average scores achieved at each test item are displayed in Tables 21 and 22 respectively, while the averages of the total scores achieved at the pre-test and post-test and scores achieved for the same test items at the pre- and post-test are shown in Table 24. In Graph 9 the comparison between students' achievement on the pre-test, post-test and achievements at the same test items on the pre- and post-test are displayed.



Graph 9
Students' achievements at the pre- and post-tests

The frequency of the mean value of total scores achieved at the pre-test was 64.65%, and the frequency of the post-test scores 62.67%, respectively, on the α-level of 1% this difference is statistically not significant (see Table 25). However, in the comparison of the frequencies only for those test items which appeared in both tests, the frequencies were 46.89% for pre-test and 70.05% for the post-test. This difference is statistically significant at the α-level of 1%, and it is possible to conclude that the hands-on approach to visible spectrometry contributed to the better understanding of some basic concepts from this field.
By using Bloom's taxonomy for the cognitive domain (knowledge) to each test item of the post-test an appropriate knowledge category was assigned. Comparison of the frequencies of the mean values achieved at each test item with Bloom's knowledge category is shown in Graph 10.

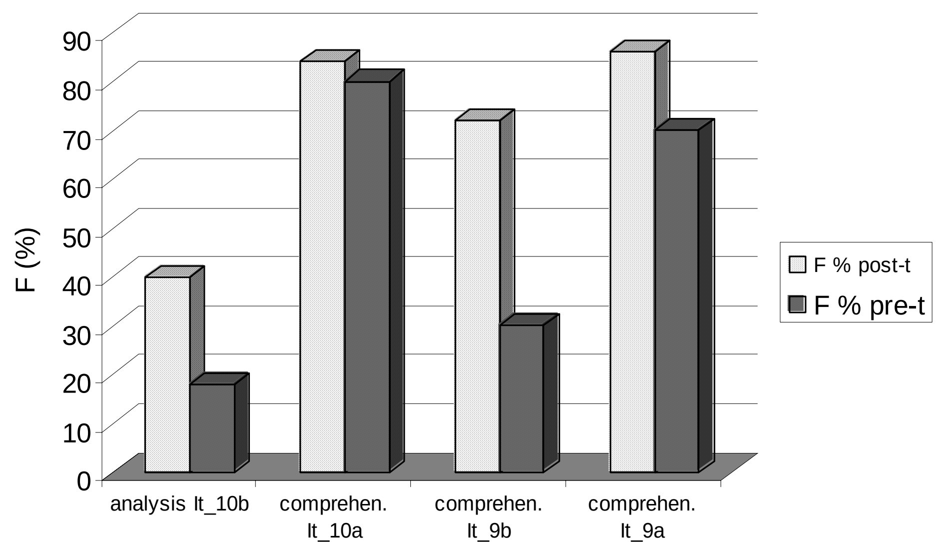


Graph 10
Bloom's knowledge categories of the post-test and mean value of frequencies

From Graph 10 a significant drop-out (from 34 up to 48%) in the frequencies of the mean values is noticed for those test items where the correct answer is based on the analysis of the problem situation, which allows for the identification of basic concepts so that their correlations may be understood (Test items 3a, 8b, 8c, 5 and 10b).

From the results displayed in Graph 3 and Table 23 we could conclude that students on the level of **recalling data or information** knew the equation for the Lambert-Beer law - 85% (Item 6). On the level of **comprehension** they were able: to deduce the relation between the wavelength of light and its colour - 55% (Item 1), to select an appropriate light emitter based on the colour of the measured sample – 66% (Item 2 a) and to justify the LED selection - 56% (Item 2b), to deduce the correlation between the transmittance and the number of layers of a filter foil - 72% (Item 4a), use the graph *transmittance/number of layers* for the determination of transmittance of a given number of filter foil layers - 88% (Item 4b), define the functional relationship between transmittance and path length of light - 84% (Item 4c), 76%

(Item 4d) and 84% (Item 4e), to select an appropriate blank for a sample of a known composition - 63% (Item 7), to determine the concentration of a sample from its absorbance and calibration line - 82% (Item 8a), to deduce the colour of additive mixing of two light beams - 86% (Item 9) and 72% (Item 9b), to compare the intensity of colour of two different volumes of coloured aqueous solutions in horizontal direction – 84% (Item 10a). On the level of **application of knowledge** students were able to select LED with the highest absorbance for a given filter foil – 56% (Item 3b). On the level of **knowledge analysis** - 53% of students (Item 3a) were able deduce the colour of filter foil from its transmittance graph for blue, green and red LED, but only 50% and 46% of students (Item 8b, Item 8c) were able to discuss reasons for the limitations in the application of a given calibration line, and even less only 40% of students, were able to correlate the impact of the path length of light on the observed intensity of colour (Item 10b).
From this analysis it is possible to conclude that the hands-on approach to visible spectrometry contributed to comprehension of the concepts tested, since for the majority of post-test items from this category the mean values of the scores achieved (frequencies) are greater than 60%. This conclusion is further supported by the results displayed in Graph 11, where the mean frequencies of the scores achieved for the same test items at pre- and post-test are shown.



Graph 11
The comparison of the achievements at the same test-items in relation with Bloom's category of the test items

The hands-on approach towards visible spectrometry contributes not only to the better comprehension, but also to the capability to analyse data (Item 10).

V.1.7 Teachers' opinion about the suitability of the didactical design of the Modules from visible spectrometry and supporting materials (Workbook for students and Teacher's guide) and impact of the approach on learning

In spite of the last vocational school reform, the tendency of which was, among others, to change the traditional teaching practice and introduce in the classroom active teaching/learning strategies and methods, lecturing is still the most often used teaching strategy in classrooms, Graph 1. This result coincides with the most often or even always used teaching method – teacher's explanation of concepts, Graph 2. The practice of testing students pre-knowledge before starting with new content is not something which should always be done; teachers use this possibility only periodically, Graph 3, but students' understanding of new concepts at the end of the lesson is often applied, Graph 3. According to teachers' opinion, the module *Measurement of light transmittance* (3.58 points) has the strongest impact on learning, while the module *Spectrometric determination of concentration* (3.00 points) has the least impact, Graph 4. Teachers appreciate the problem-based structure of the modules (4.17 points) and their systematic and comprehensive structure (3.75 points), Graph 5. They appreciate (4 or more points) all elements of the study modules, but from their perspective, especially useful is the *Teacher's Guide* (4.42 points), Graph 6. This opinion is in line with the results displayed in Graph 7, since in preparation for the hands-on approach to visible spectrometry their special attention was paid to instructions in the Teacher's Guide (4.75 points), preparation of materials, reagents and instruments for practical work (4.58 points) and student's understanding of concepts presented (4.25 points).

V.1.7 Teachers' suggestions and proposals for changes in the design of the modules in order to achieve better learning outcomes

At the end of the teacher's questionnaire teachers were asked to stress the most important advantages of using modules from *Hands-on Approach to Visible Spectrometry* that they observed during carrying out the approach in the classroom, to present the encountered problems and to give suggestions to avoid these problems in the future. We were able to collect information only from four Slovene teachers, since we did not get the transcription of suggestions from the Polish partner. Slovene teachers stress a series of advantages of the tested approach: deduction of regularities from the experimental results, discovery based approach, high students' motivation level throughout the experimental work, great variety of experiments, teacher's control of the class activity by using special visual support, which enables them to give to the students immediate feedback after any phase of the experimental procedure. In presenting problems, teachers were either too polite or they did not want to expose themselves. The only disadvantage mentioned by two teachers is the time consuming experimental work. In this comment the mode of traditional thinking of Slovene teachers is reflected, namely that the most valuable and awarding approach in teaching is lecturing, since a lot of concepts could be presented in the short time available. In contrast to this opinion are the findings of Stohr-Hunt that those students who were engaged in hands-on activities every day or once a week scored significantly higher on the standardized test of science achievement than students who were exposed to hands-on activities only occasionally or never. Among the suggestions for changes, two were specially emphasized: to prepare more study materials in a similar way, and to design modules on different levels of difficulties.

V.2 Strengths and weaknesses of the study

Among strengths of the study the following could be emphasized:

- the methodology selected for carrying out the evaluation, materials and instruments used in this study;
- the selected modules from visible spectrometry were designed and reviewed by the experts in the field of analytical chemistry and didactics during the course of the first project AnalChemVoc, and preliminary evaluation of the modules in the classroom settings was also carried out. Based on these results some modifications of the teacher's guide and student's workbook were made prior to the start of the evaluation study;
- knowledge tests (pre- and post-test) were standardized and amended accordingly;
- all teachers got a detailed description of the evaluation study procedure in order to enshure an uniform approach;
- the results obtained are in line with research findings of other studies on the impact of motivational orientations on the students' academic achievements as well as the hands-on approach on science attitudes and competences, and

- the inclusion of personal variables (e.g., students' motivation and self-concept), which enriches the research approach through the sociocognitive theory of learning and teaching.

Weaknesses of the study:

- demographic coverage did not encompass all partners in the project. The partner from the UK did not have the possibility to work with the selected modules, due to his involvement in a series of other outreach activities at the University of Bristol, therefore only the test for motivation was used;
- in spite of the decision that four modules from the *Hands-on approach to visible spectrometry* would be tested, since the concepts included in these modules are interrelated, some teachers introduced in the classroom only three modules, the last one or the first one were omitted, but in the post-test concepts from all four modules were included;
- the number of hours dedicated to the execution of modules also differs from school to school (4-8h),
- a direct observation of the classroom activities during the execution of the modules might give a more realistic insight into students' acceptance of the modules, since teachers were sparing with their words in describing the real classroom situations during the work with modules, and
- further monitoring and supporting of teachers is needed in everyday use of new approaches in the classrooms.

V.3 Results in relation to other studies

A series of studies (Chiu, Chou, & Liu, 2002; McCarthy, 2005; Moore, 2006; O'Neill, & and Polman, 2004; Vrtačnik, & Gros, 2005) dedicated to the impact of the hands-on approach to science teaching proved that hands-on science programs in the classrooms offer many benefits to students: i.e. increased learning, motivation to learn, enjoyment of learning; skill proficiency, including communication skills; increased independent thinking and decision making based on direct evidence and experiences; and increased perception and creativity. Students in activity-based programs have exhibited increases in creativity, positive attitudes toward science, perception, logic development, communication skills, and eagerness to read. The results of our study indicate that the hands-on approach, when it is properly guided and stimulated by the teacher, contributes to comprehension of concepts taught and also to the ability to apply knowledge in a new situation. However, we found out that the students' academic achievements and their attitude towards the hands-on approach in learning science are closely related to their motivational orientations and study program. These results are supported by research outcomes of several authors (e.g. Rattelle, Guay, Vallerand, Larose, & Senécal, 2007; Fortier, Vallerand, & Guay, 1995; Grolnick, Ryan, & Deci, 1991, , Guay, & Vallerand, 1997; Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004; Vrtačnik, Juriševič, & Ferk, 2010), that have proven that autonomous academic motivation is positively associated with academic achievements. Our research results revealed that the good quality motivation group of students (high autonomous and low controlled motivation) achieved statistically significant better results on the post-test than the low quantity motivation group (low autonomous and controlled motivation). Examination of different aspects of motivation in the domain of education has shown that in classrooms in which teachers were autonomy-supportive, as in the case of the hands-on approach to visible spectrometry, students were more intrinsically motivated, they also felt more competent at school work and achieved greater learning performance (Chirkov, & Ryan, 2001; Vansteenkiste, Simons, Lens, Sheldon,& Deci, 2004). Despite all these benefits, research by Hassard (1992) revealed that the use of hands-on activities is far less frequent than lecture and discussion. Weiss (1987) found that the major obstacles are science teachers who are reluctant to use active teaching strategies, since these are, according to their claims, time and materials consuming. After more than 20 years this claim is still present among teachers. In our study, as a major draw back of the hands-on approach, teachers stressed the time consuming realization. In our study we also proved that teachers are still very much inclined to lecturing on science, but they would be willing to use active teaching strategies more often if more didactical materials were available.

V.4 Meaning and generalisabilty of the study – recommendations

The results of the evaluation study allows for the recommendation to apply small-scale low-cost spectrometers (e.g. Spektra^{TM}) that can be easily upgraded into other analytical instruments, e.g. gas and liquid chromatographs, in the school practice of teaching chemistry, chemistry-related and chemistry-based disciplines, together with hands-on teaching units and several newly developed hands-on experiments. The study proved that the hands-on approach supports an autonomous teaching style, which could, if used more frequently, contribute to increased autonomous motivation and thus to better academic achievements and self-concepts.

V.5 Unanswered and new questions

The results of the study offered answers to all questions stated among the goals of the study, but a series of new questions emerged. Only a few of them are presented below.

- What changes in the students' motivational orientations (i.e.profiles) would be detected if students had the possibility to experience the hands-on approach in learning science more frequently?
- Does the hands-on approach in science teaching contribute to the permanence of knowledge, and to which Bloom's category of knowledge?
- Could the hands-on approach to science teaching contribute to changes in science attitudes and values?

VI Conclusions

The Leonardo da Vinci international project Hands-on Approach to Analytical Chemistry for Vocational Schools II (AnalChemVoc II), which was launched in November 2008, envisaged as one of the important project outcomes the evaluation study on the impact of the hands-on approach to visible spectrometry on students' academic performance in correlation with students' motivational orientations. In the study 295 students took part, 92 from Polish vocational and technical high schools and 203 from Slovenia. For 104 students from the Bristol area, only the test on motivation was obtained, since they did not work with the selected modules, therefore only motivational orientations of British students were deduced, without any further implication. For the purpose of the study four modules from the Hands-on Approach to Analytical Chemistry, which were developed during the course of the first project AnalChemVoc (2003-2005), were selected. The modules were designed to introduce the students of vocational schools to the basic concepts from visible spectrometry through a carefully structured hands-on approach. As the instruments of the study, the standardized pre- and post-test, and a 50-item questionnaire for assessment of students' motivation and attitudes were used. In order to identify the number of clusters in the data set, based on the motivational dimensions defined by controlled and autonomous motivation, *k-mean*s clustering was used. The results revealed two distinct motivational orientations (i.e., profiles): cluster I – low quantity motivation group (with low autonomous and controlled motivation) and cluster II – high quality motivation group with high autonomous and low controlled motivation.

Students' cluster membership is reflected in their academic achievements, since a statistically significant difference between the low quantity and good quality motivation groups of students at the α-level of 1% was found for achievement on the post-test, and at the α-level of 5% for prior academic achievements, while on the pre-test the difference between groups was not found statistically significant. Cluster membership is also reflected in the students' attitude towards the hands-on approach that they experienced while working with modules from visible spectrometry. The high quality motivation group assigned higher scores to all didactical elements of the approach. According to their statements they also gained more specific knowledge and skills, while opinions on the safety aspects of the selected experiments are weighted equally by both motivational groups of students.

Further, the study showed that apart from students' motivational orientations, the study program also influenced the students' academic achievements. One-way ANOVA revealed statistically significant differences at the α-level of 1% between all participating schools on academic achievements at the pre-test, post-test and also in prior achievements. The best results at the pre-test and post-test were achieved by the students enrolled in the chemistry technician program; such a result was in accordance with our expectations, since these students should have more solid prior knowledge of chemistry than students from other vocational programs.

From the perspective of Bloom's knowledge category, our study showed that the hands-on approach towards visible spectrometry contributes not only to the better comprehension of concepts, but also to the capability to analyse data.

Teachers responses to the hands-on approach, which were collected by applying the special questionnaire, stress a series of advantages of the tested approach, among them: deduction of regularities from the experimental results, discovery based approach, high students' motivation level throughout the experimental work, great variety of experiments, teacher's control of the class activity by using special visual support, which enables them to give to the students immediate feedback after any phase of the experimental procedure. Teachers made a proposal to prepare additional teaching materials in the form of the hands-on approach at different levels of difficulty, so that less able students would not be left behind.

Authors' contributions

Dr. Margareta Vrtačnik – first author of the evaluation study, responsible for the design and management of the evaluation study, co-author of instruments, in-put raw data from Slovenian high schools, harmonizing data and data analysis

Dr. Mojca Juriševič – author of the motivation test, responsible for analysing the contribution of personal variables to the results of the study

Dr. Nataša Gros – leading author of the study (promoter of the project – responsible for the execution of the project in Slovenia, Poland and UK, and on-time achievements of the project's goals), co-author of the knowledge tests

Dr. Marek Kwiatkowski **–** translation of the modules from the »Hands-on Approach to Analytical Chemistry for Vocational Schools«, and instruments of the study into the Polish language, responsible for organizing the execution of the study in Poland

Tim Harrison – responsible for the execution of the study in UK.

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Acknowledgement

The authors wish to thank the financers of this project, Leonardo da Vinci, and especially all participating students and teachers, without whose dedication and willingness to cooperate the realization of the project would not have been possible.

Appendices

1. Motivation test
2. Knowledge tests