Chemical education research paper

The Impact of a Hands-on Approach to Learning Visible Spectrometry Upon Students' Performance, Motivation, and Attitudes

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Received: 27-09-2012

Abstract

In this paper, the effect of introducing visible spectrometry concepts through hands-on laboratory work upon student learning within four vocational programs are discussed. All together, 118 students, average 18.6 years old, participated in the study. The results showed no correlation between students' motivational components (intrinsic, regulated, and controlled), chemistry self-concept and their achievement on an experiential knowledge test and knowledge gained from this hands-on approach. Statistically significant differences were found for academic achievement among students in a biotechnology technical program (School 1), food processing program (School 2), laboratory biomedicine program (School 3), and a biotechnology general program (School 4). Differences in academic achievement are further reflected in students' perception of particular knowledge gained through their hands-on experiences and in their expressed attitude toward different didactical characteristics. All students, regardless of their study program, highly evaluated the relaxed atmosphere that contributed to their self-confidence in completing their laboratory activities.

Keywords: Hands-on approach, visible spectrometry, academic achievement, motivation, self-concept

1. Introduction

A basic characteristic, of chemistry knowledge is that the body of chemical information is growing exponentially. This ever-increasing body of chemical knowledge poses challenges for educators, since it is apparent that chemical curricula does not reflect the state of current chemistry practice.[1] A serious criticism often made is that what is taught today in classrooms is not real-life chemistry, but merely a history of chemistry.[1] This claim can be regarded as valid only if education is considered primarily as a process of transmission of data and information (i.e., pouring data into students' empty heads). However, by contrast, if education is regarded as an active teaching and learning process, then stress must be placed on those learning and teaching strategies that encourage students to become engaged in higher-order thinking processes such as discovery, analysis, synthesis, and evaluation, rather than memorizing data and information (rote learning). The overall quality of teaching and learning could be improved if students are given opportunities to clarify, question, apply, and consolidate new knowledge. To achieve active engagement of students, a variety of student-centred instructional strategies are emerging, 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-playing, journal writing, concept mapping, structured learning groups, cooperative learning, collaborative learning, inquiry-based learning, and hands-on approaches to teaching and learning.[2–9] The last strategy is especially suitable for learning in the experimental sciences, such as chemistry or chemistry-related subjects.

1. 2. Hands-on/Minds-on Science Teaching

Instructional approaches in science that involve activity and direct experiences with natural phenomena have become known as *hands-on science*, defined as any educational experience that actively involves students in manipulating objects.[10] However, a hands-on approach not only engages students in activities, it also provokes their curiosity and thinking. Therefore a new aspect has been added to previous implications of hands-on science, namely, *hands-on/minds-on science*.[10–12]

A hands-on strategy should not be confused with an inquiry-based approach, since these terms are distinctly different. Instruction in inquiry-based classrooms involves a variety of methods – discussions, investigative laboratory activities, laboratories, debates, lectures, and also the hands-on approach.[13] In a hands-on approach, students work directly with materials and manipulate physical objects i.e., they are engaged in experiencing science phenomena, while inquiry- or discovery-based learning involves thinking, reading, writing, or research that enhances meaning to hands-on strategies.[14]

In teaching and learning chemistry-based and chemistry-related subjects, hands-on supported laboratory work is of special importance, due to the abstract language and symbolic conventions of chemistry, which require establishing links between the theoretical (abstract) and observable (practical) aspects of topics taught.[12] In addition, through hands-on laboratory work, learning goals such as subject-matter mastery; improved scientific reasoning, understanding that experimental work is complex and can be ambiguous, and an enhanced understanding of how science works, can be attained.[15] A hands-on approach to laboratory work also enables development of a range of generic competences and skills: manipulation of equipment, experimental 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.[16,17] However, despite efforts to incorporate hands-on strategies in laboratory work, many, if not most, science classrooms remain places where students receive pre-packaged knowledge from teachers through direct transmission and/or carefully orchestrated learning activities.[18] Major obstacles are those science teachers who are reluctant to employ active teaching strategies, since, it is claimed, they are time and materials consuming. Thus, such teachers do not implement these strategies in their courses, which instead, are overloaded with content.[19] The situation is even more critical in vocational and technical schools, since European vocational education, especially in chemistry-based and chemistry-related disciplines, is experiencing a crisis, as reflected in low enrolment rates, under-funding that, in turn, leads to inadequate analytical instrumentation, changes in structure, and weakened student motivation.[20]

We addressed these problems through two EU projects entitled "Hands-on approach to analytical chemistry for vocational schools" (2003–2005 and 2008–2011). We challenged the often misleading perception that there is only one way to support analytical chemistry instruction, i.e., with complicated and costly professional instrumentation. And, if a school or university does not possess such instrumentation, or has no access to it, there is no other way to proceed. The solution that we explored is based on a low-cost spectrometer with a microreaction chamber and a tri-colour light-emitting diode as the light source, which was developed by the projects' coordinator and co-author of this paper.[21] This spectrometer can be readily upgraded into several different analytical instruments, all of which enable a sound introduction to the fundamentals of instrumental analytical methods using a hands-on approach and thus give schools of different types and educational levels opportunities to assess more than 60 laboratory experiments representing different applications and to develop their own real-life applications.[22]

The starting point for construction of a tri-colour, light-emitting-diode-based, in-situ spectrometer was a decision to use polymeric supports, called blisters–used in the pharmaceutical industry for packaging of pastilles–as the reaction and measuring chambers. A tri-colour light-emitting diode (LED) functions as a light source; blue, green, or red light can be selected. The geometry of the spectrometer allows the light to pass through the solution vertically and fall directly onto a photo-resistor, which is positioned under the microreaction chamber.[23] The equality of the light's path length within a series of measurements is achieved by controlling the volume of the solutions in individual blister hollows, e.g., by use of micropipettes for measuring the sample and reagent volumes or by use of a simplified drop-based experimental approach. Experiments can be completed rapidly and do not require laboratory environment or any classical laboratory skills. Measurement results are expressed in terms of the transmittance. Experiments demonstrating the additive mixing of colour can also be performed with tri-colour LED. The spectrometer is intentionally designed so that it contributes to developing mathematical competence and basic competences in science and technology. Students are in direct contact with what is being measured and receive only "raw data" from the spectrometer. They must apply different mathematical procedures (e.g., draw graphs, calculate with fractions or linear equations; apply logarithms) to obtain final results of the analyses or to recognise trends. The prototype of this spectrometer was transformed into the Spektra™ (Laboratorijska tehnika Burnik d.o.o., Skaručna, Slovenia); this version of the spectrometer was implemented in schools through the projects described in this paper.

One product of the first EU project was a teaching unit, "Hands-on Approach to Visible Spectrometry", based on the small-scale spectrometer, Spektra™. The teaching unit was developed in several stages in cooperation with teachers of three Slovenian vocational schools of agriculture and food processing who tested the unit with their students and provided a valuable feedback. The teaching unit includes these modules: 1. Light as radiation; 2. Light and colour perception; 3. Colour of substance and light transmittance; 4. Colour, absorption spectrum and colour of a substance; 5. Measurement of light transmittance; 6. Spectrometric determination of concentration; 7. Practical application of visible spectrometry; 8. Visible spectrometry as a means for better comprehension of fundamental chemical concepts. Each module is supported by a teacher's guide, student' workbook, and PowerPoint presentation, which enable teachers to guide students in completing activities included in the modules, and to provide immediate feedback on the correctness of students' interpretations of experimental results. The approach involves student pairs independently completing experiments with Spektra™ spectrometers, without any major teacher's interventions, following the provided written instructions. They measure, observe, record measurements, calculate, draw graphs, and formulate conclusions, and by doing so, they progress from the fundamentals of visible spectrometry into its applications. The impact of this teaching unit's design on students' performance, motivation, and attitudes was systematically evaluated through the second EU project. The results of this study are presented in this paper.

1. 3. The Role of Motivation on Students' Leaning Outcomes

According to the contextual paradigm of learning and teaching, it is important to attend to students' personal characteristics affecting learning; among them, motivation plays an extremely important role.[24,25] Namely, in the last decade, student motivation has been targeted by teachers, parents, and researchers as a key factor determining whether or not students succeed in school. The central focus of motivation research is, therefore, on conditions and processes facilitating the persistence, performance, healthy development, and vitality of instructional endeavours. Research is fairly consistent in showing that motivation influences cognitive and metacognitive processes amongst students and thus stimulates higher levels of thinking and determines an individual's attitude and approach to learning and to activities that can lead to more meaningful learning.[24,25]

Most theories have regarded motivation as a unitary concept that varies in its extent. However, by contrast, the Self Determination Theory (SDT) of motivation has uncovered new insights and dimensions of motivation.[26,27] The theory focuses on motivational orientation or types, rather than just on the extent of motivation, paying particular attention to autonomous motivation (intrinsic and regulated), controlled motivation, and motivation as a predictor of performance, relational, and well-being outcomes.[28] Motivation is thus regarded as a multidimensional concept that varies in terms of *quality*. Student motivation is considered to be high-quality when it is primarily based on autonomous motivation, i.e. intrinsic, identified, and integrated regulation, and it is regarded to be poor quality when it is based on controlled motivation, i.e. external and introjected regulation.[29] A series of research findings have established that autonomous academic motivation is positively associated with academic achievement.[30–33]

In addition, research findings have revealed that some types of motivation are subject-specific, whereas others are not; for example, intrinsic motivation differed in intensity for mathematics, writing, and reading.[34] Furthermore, autonomous motivation is more apparent when students experience satisfaction in their basic psychological needs for competence, relatedness, and autonomy. Examination of different aspects of SDT in the domain of education has shown that in classrooms where teachers were autonomy-supportive, students were more intrinsically motivated, they also felt more competent at school work, and so they held higher self-concepts. An autonomy-supportive teaching style also leads to greater learning performance outcomes than does a controlling style.[35, 36]

2. Study Goals and Research Questions

The major goals of this study were: (a) to introduce basic concepts of visible spectrometry through a hands-on laboratory approach to students from selected vocational and technical schools (more specifically, students of food processing, biotechnology and laboratory biomedicine), and to evaluate the impact of such an approach on students' knowledge and attitudes; (b) to seek correlations among students' academic achievement, their motivational components (intrinsic, regulated, and controlled), and chemistry self-concept.

To attain these goals, the following research questions were formulated:

1) How are students' motivational components (intrinsic, regulated, and controlled motivation) and their chemistry self-concept correlated with their experiential knowledge of visible spectrometry (knowledge gained through personal experiences with light and colour) and knowledge gained through a hands-on approach to visible spectrometry?
2) Are there differences in motivational components between students enrolled in different vocational study programs?
3) What impact does the study's program have on students' knowledge gained through a hands-on instructional approach to visible spectrometry?
4) What impact does the study's program have on students' perception of specific knowledge and skills gained through a hands-on approach?
5) What impact does the study's program have on students' opinions about didactical components of the completed instructional modules in visible spectrometry?

2. 1. Materials and Research Design

The procedure of selecting schools and vocational programs was such that before applying for a grant for the second EU project, the applicant and the prospective project's coordinator organized with assistance of the Centre of the Republic of Slovenia for Vocational Education and Training, a meeting to which representatives of all Slovenian vocational schools including educational programs which featured visible spectrometry were invited. The project's objectives were presented to teachers and they were invited to join the project. The vocational schools that responded became project partners and were provided through the project Spektra™ spectrometers and the teaching unit, "Hands-on Approach to Visible Spectrometry" in a CD format. The coordinator ensured, with the financial support of the Ministry of Education, that schools received sufficient spectrometers, to meet the requirement that, for an instructionally efficient hands-on approach, each pair of students should work with their own spectrometer. The schools that joined the project well represented all study programs for which analytical chemistry and visible spectrometry were relevant. Teachers from participating schools participated in the workshop organized at the faculty of Chemistry and Chemical Technology, University of Ljubljana. They experimentally tested each module of the teaching unit, and were introduced to the research plans.

The visible spectrometry content that introduced students *via* a hands-on approach consisted of four modules selected from the "Hands-on Approach to Visible Spectrometry": *Colour of Substances and Light Transmittance, Measurement of Light Transmittance, Spectrometric Determination of Concentration, and Practical Application of Visible Spectrometry*.[37] The basic goals of the selected modules were to introduce students through a hands-on approach to these concepts and procedures: (a) relationship between the colour of a material and the transmittance of light of different wavelengths, (b) selection of the correct light emitter for measuring the transmittance of light through a coloured medium, (c) the concept of transmittance (T) as a ratio between the radiation power transmitted by the absorbing medium (ϕ) and the radiation power incident on the absorption medium (ϕ_o), (d) a procedure for measuring transmittance in various absorption media (filter foils, coloured liquids), and the role of a blank, (e) experimental development of the Lambert-Beer's Law, (f) application of visible spectrometry for determining the concentration of a substance in real samples, and (g) the importance of calibration in spectrometric analyses.

Student work started in April 2010 and finished in June 2010. Teachers from participating schools were free to select within that time interval, the particular date when they began using the modules and submitting tests.

Prior to starting practical work, students' knowledge of visible spectrometry gained through personal experiences was assessed using an experiential knowledge test (EXT). After completion of the four modules (each required, on average, 2 hours, 45 minutes), a knowledge test (KT), and the Students' Motivational Orientation and Perception Questionnaire were administered. All instruments were completed within regular chemistry classes. The EXT and KT were evaluated by two independent Slovene evaluators, full time professors of chemical education.

2. 2. Instruments

A 50-item questionnaire to assess students' motivation and perception of the hands-on approach to visible spectrometry was constructed on the basis of two questionnaires used in previous research.[38–41] Specifically, the questionnaire was designed to assess: (a) 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), and (b) students' reasons for preference regarding the instructional method used in the study. Classroom administration of the questionnaire took approximately 15 minutes; students were asked to respond to a series of simple declarative sentences on a 5-point Likert scale, *ranging from 5 – very true for me, to 1 – not at all true for me*.[38–41] Internal consistency for items from the first part of the questionnaire that formed three composite variables was verified with the calculation of Cronbach's α coefficient and regarded as satisfactory i.e. $\alpha_{controlled\ motivation} = 0.67$, $\alpha_{autonomous\ motivation} = 0.80$, and $\alpha_{chemistry\ self\text{-}concept} = 0.89$, respectively. Items from the second part of the questionnaire assessing students' perception of the instructional method used and specific knowledge and skills gained through the hands-on approach were descriptively analysed (*i.e.,* frequencies and percents). For assessment of the impact of the hands-on approach to visible spectrometry on students' knowledge, an experiential knowledge test - EXT (with 12 short items, total scores 5.75) and a knowledge test – KT (with 20 short items, total scores 10.75) were designed. Construction of both assessments was accomplished in a preliminary study in which 30 students and two teachers participated. Both instruments were semi-standardised through item analysis; test items with a difficulty factor of around 0.5 and discrimination coefficient ranging from 0.3 to 1 were selected for the final instruments.

2. 3. Sample

A total of 118 students (M = 45, F = 73), average age 18.6 years, participated in the study, representing the vocational study programs presented in Table 1.

Table 1: Participating students and their study programs

School	Hours of general chemistry in the first and second year	Technical study program	Number of participating students
SCHOOL 1	140	Biotechnology program – technical	45
SCHOOL 2	105	Food processing program	28
SCHOOL 3	204	Laboratory biomedical technician	27
SCHOOL 4	140	Biotechnology program – general	18
		Total	118

Students were from three Slovenian regions (Central, Northern and Western).

3. Results and Discussion

3. 1. The Impact of Motivation on Students' Academic Achievements

Correlations at the 0.01 level of significance were found between all motivational components and chemistry self-concept (Table 2). However, differences in motivational components and self-concept failed to correlate with students' academic achievement or experiential knowledge at that significance level.

However, students with more personal experience with light and colour achieved better KT results, since the correlation between EXT and KT results was significant at the 0.05 level (Table 2). This result is not in line with prior research findings, where strong correlations between students' academic achievement and autonomous motivation (intrinsic and regulated) have been reported.[30–33] Therefore, a one-way ANOVA analysis was conducted to attain better insight into how mean values of motivational components and self-concept differ among students from the four schools. Group statistics for motivational components, self-concept, and the significance of any differences among school results are displayed in Table 3.

Mean values of weights assigned to motivational components by students of different schools for intrinsic motivation are below 3, while for regulated motivation they are slightly above 3. Based on these results (Table 3), it is possible to conclude that regardless of school or school program, the quality of students' academic motivation is poor, which may be regarded as a major reason why no significant correlation between motivational components and test results were found.[29] Statistically significant differences ($p < 0.05$) were found only for regulated motivation, as suggested by the mean value of 3.67 for School 3 students (Table 3).

Even though motivation and chemistry self-concept were not associated with observed differences in students' academic achievement, statistically significant differences among schools ($p < 0.01$) were found for EXT and KT results (Table 4).

Table 2: Pearson correlation coefficients between different component of motivation, self-concept and academic achievements at EXT and KT

		EXT	KT	Intrinsic	Regulated	Controlled	Self-concept
EXT	Pearson Correlation		0.209*	–0.15	0.03	0.13	0.03
	Sig. (2-tailed)		0.02	0.11	0.76	0.16	0.75
	N		118.00	118.00	118.00	118.00	118.00
KT	Pearson Correlation			0.01	0.12	0.01	0.16
	Sig. (2-tailed)			0.90	0.20	0.91	0.08
	N			118.00	118.00	118.00	118.00
Intrinsic motivation	Pearson Correlation				0.722**	0.323**	0.680**
	Sig. (2-tailed)				0.00	0.00	0.00
	N				118.00	118.00	118.00
Regulated motivation	Pearson Correlation					0.402**	0.665**
	Sig. (2-tailed)					0.00	0.00
	N					118.00	118.00
Controlled motivation	Pearson Correlation						0.363**
	Sig. (2-tailed)						0.00
	N						118.00

Table 3: Descriptive statistics for motivational components and self-concepts for schools

Motivational components	Schools	N	Mean	Std. Deviation	One-way ANOVA F	Sig.
Intrinsic	SCHOOL 1	45	2.53	1.01		
	SCHOOL 2	28	2.63	0.70	1.86	0.140
	SCHOOL 3	27	2.94	1.04		
	SCHOOL 4	18	2.35	0.65		
	Total	118	2.62	0.91		
Controlled	SCHOOL 1	45	3.13	0.58		
	SCHOOL 2	28	2.79	0.50	2.67	0.51
	SCHOOL 3	27	2.93	0.57		
	SCHOOL 4	18	2.85	0.49		
	Total	118	2.96	0.56		
Regulated	SCHOOL 1	45	3.13	0.79		
	SCHOOL 2	28	3.06	0.75	4.13	0.008
	SCHOOL 3	27	3.67	0.69		
	SCHOOL 4	18	3.17	0.55		
	Total	118	3.24	0.76		
Chemistry self concept	SCHOOL 1	45	3.20	1.11		
	SCHOOL 2	28	3.05	0.73	1.01	0.389
	SCHOOL 3	27	3.47	0.90		
	SCHOOL 4	18	3.19	0.50		
	Total	118	3.23	0.91		

Further analysis, comparing differences in students' achievement from the same school on the EXT and KT revealed that the overall statistical significance could be attributed primarily to differences in student achievement in Schools 2 and 4 (Table 5).

Students from Schools 2 and 4 achieved lower EXT scores compared to students from Schools 1 and 3 (mean values of 37.58 and 59.03, respectively), but after the hands-on approach intervention, their improvement in mastering concepts of visible spectrometry was greater than for students in Schools 1 and 3; mean values of KT results were 57.23 and 68.99, respectively. These results are supported by previous research findings, that through hands-on laboratory work, learning goals such

Table 4: Descriptive Statistics – differences between schools in students' achievements on experiential and knowledge tests and staistical significanct of diffrences

Tests	Schools	N	Mean	Std. Deviation	One-way ANOVA F	Sig.
Intrinsic	SCHOOL 1	45	2.53	1.01		
Experiential	SCHOOL 1	45	73.52	16.59		
knowledge (EXT)	SCHOOL 2	28	37.58	16.64	15.27	0.000
	SCHOOL 3	27	67.47	26.19		
	SCHOOL 4	18	59. 03	13.76		
	Total	118	61.40	22.07		
Knowledge gained	SCHOOL 1	45	74.00	11.37		
through hands-on	SCHOOL 2	28	57,23	17.25	7.60	0.000
approach (KT)	SCHOOL 3	27	70,71	16.01		
	SCHOOL 4	18	68,99	10.85		
	Total	118	68.51	15.15		

Table 5: Statistically significance of differences between EXT and KT knowledge tests results

		Paired Differences Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
SCHOOL 2	KT-EXT	19.65	21.76	4.11	4.78	27	0.000
SCHOOL 4	KT-EXT	9.96	16.09	3.79	2.63	17	0.018

as subject-matter mastery and improved scientific reasoning can be attained.[15,16] The hands-on approach to visible spectrometry allowed students from these two schools to master new concepts more successfully, despite their low experiential knowledge and motivational characteristics.

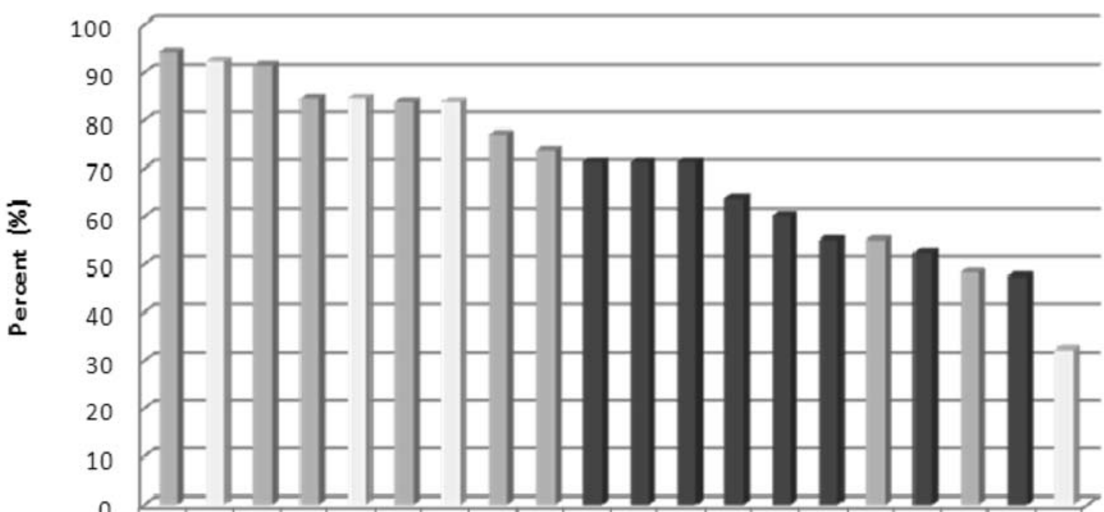
3. 2. Impact of the Hands-on Approach to Learning Visible Spectrometry on the Quality of Student Knowledge Gained

The following basic concepts were included in the EXT: conditions for colour perception, additive mixing

Table 6: Structure of experiential knowledge test (EXT) and statistically significance of differences in students' achievement at each test items between schools

EXT Test item	Concepts and their relation	N	Mean	ANOVA F	Sig.
1.	Conditions for colour perception	118	0.22	1.46	0.230
2.	Conditions for colour perception	118	0.21	2.11	0.103
3.	Conditions for colour perception	118	0.31	7.71	0.000
4.*	Additive mixing red and blue light	118	0.31	4.55	0.005
5.*	Additive mixing red and green light.	118	0.18	8.63	0.000
6.	Effect of dilution of coloured solution on concentration.	118	0.45	2.47	0.066
7.	Effect of dilution of coloured solution on colour intensity.	118	0.35	5.01	0.003
8.	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – horizontally	118	0.40	12.85	0.000
9.	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – horizontally	118	0.40	20.38	0.000
10.	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – horizontally	118	0.30	8.48	0.000
11.*	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – vertically	118	0.36	16.32	0.000
12.*	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – vertically	118	0.05	1.41	0.243

* Test items included in EXT and KT tests



	K 12	C 17	C 14	C 8	C 18	C 7	C 19	C 9	C 10	C 2	C 6	C 13	C 3	C 1	An 4	An 15	Ap 5	An 11	An 16	An 20
Percent	94	92	92	85	85	84	84	77	74	71	71	71	64	60	55	55	53	48	48	32

Graph 1: Bloom's knowledge categories of the KT and percent of students who solved test items correctly

Legend: K (Knowledge); C (Comprehension); An (Analysis); Ap (Application) Bars: deep grey (items where statistically significant differences between schools were detected); medium grey (items where no statistically differences identified); light grey (items which were the same in both tests).

Table 7: Structure of knowledge test (KT) and statistical significance of differences in students' achievement at each test items between schools

KT Test item	Concepts and their relation	N	Mean	One-way ANOVA F	Sig.
1.	Wavelength of light and colour.	118	0.60	28.54	0.000
2.	LED selection – colour of absorption medium.	118	0.36	9.95	0.000
3.	Justification of LED selection	118	0.32	2.96	0.035
4.	Deduction of colour of a filter foil from its ransmittance (*T*) graph for red, green and blue LED.	118	0.28	12.66	0.000
5.	Selection of LED with the highest absorbance.	118	0.26	3.47	0.019
6.	Correlation of *T* / and number of layers of a filter foil.	118	0.18	7.58	0.000
7.	Using the graph *T*/ and number of layers for determination of transmittance	118	0.21	0.79	0.503
8.	Functional relation between *T*/and number of filter foils.	118	0.21	2.14	0.099
9.	Functional relation between *T*/and number of filter foils.	118	0.19	1.06	0.367
10.	Functional relation between *T*/and number of filter foils.	118	0.18	2.20	0.092
11.	Transmittance/Absorbance and concentration of the absorption medium correlation.	118	0.48	1.65	0.181
12.	Equation of the Lambert-Beer Law.	118	0.94	0.12	0.950
13.	Selection of the blank.	118	0.71	4.69	0.004
14.	Determination of concentration from the calibration line.	118	0.46	0.14	0.937
15.	Limitations in the use of a displayed calibration line in relation with the concentration of the absorption media.	118	0.28	2.50	0.063
16.	Limitations in the use of a displayed calibration line in relation with the concentration of the absorption media.	118	0.24	4.93	0.003
17.*	Additive mixing of red and blue light.	118	0.46	0.38	0.765
18.*	Additive mixing of red and green light.	118	0.42	0.24	0.869
19.*	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – horizontally.	118	0.42	4.91	0.003
20.*	Effect of dilution of coloured solution on colour intensity in relation to the direction of observation – vertically.	118	0.16	0.87	0.458

of beams of light of different colours, effect of diluting a coloured solution on concentration, and colour intensity related to angle of observation of the coloured samples and their volumes. Our assumption was that the majority of targeted concepts should be known by students either from their personal experiences with light and colour or previous experimental work. Identification of concepts included in the knowledge test (KT) administered after the intervention 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 and use of these concepts: transmittance in relation to concentration of samples, length of the light path through the sample, relationship between transmittance and absorbance, use of a calibration curve for determining concentration, composition of the blank relative to composition of the sample, and light-emitter LED selection in relation to the sample's colour. Four test items in the EXT and ET were identical. The detailed structure of the EXT and KT, mean scores attained for each test item, and results of a one-way ANOVA to identify any differences in students' mean achievement for each test item among schools are displayed in Tables 6 and 7.

Of 12 test items included in the EXT, for 66.7% of them (8 items), statistically significant differences among schools at the 0.01 or 0.05 level were detected (Table 6). While for the knowledge test, only for 45% of test items (9 of 20) statistically significant differences in students' achievement among schools at the 0.01 or 0.05 level were identified (Table 7).

Bloom's taxonomy[40] for the cognitive domain (knowledge) was used to classify KT items. Comparison of the percent of students who solved correctly test items at each Bloom's knowledge level is displayed in Graph 1.

A significant decline (from 55% to 30%) in the proportion of students who successfully solved test items (4, 15, 5, 11, 16, 20) is noted (Graph 1). For these items, answers could be deduced from **analysis** of the problem situation, which requires identification of basic concepts and their relationships.

These results are consistent with published findings,[41] where significantly higher student performance for questions of factual recall were reported than for questions assessing comprehension or application skills. Knowledge of specific deficiencies in student performance may be helpful in shaping future course instruction and assessment, since student-centred instructional approaches contribute to better knowledge retention and understanding compared to more conventional teaching approaches.[44]

3. 3. The Impact of Study Students' Program on Perception of Specific Knowledge and Skills Gained Through the Hands-on Approach

We were further interested in how students' perception of specific knowledge gained through the hands-on approach to visible spectrometry differ among schools and study programs. Group statistics and results of a one-way ANOVA for the statistical significance of differences are shown in Table 8.

Among schools, students' perception of specific knowledge and skills gained through the hands-on approach to visible spectrometry revealed statistically significant differences at the 0.01 or 0.05 level for all knowledge categories (e.g. understanding correlation between colour of matter and light absorption of light, basic principles of LED selection, role of the blank, relationship between *T*/*A*, handling the instrument, use of spectrometry for determining concentration). Students from Schools 1 and 3 earned the highest mean scores for all knowledge and skills categories; their superiority is supported by results in the EXT (School 1 – 73.52% and School 3 – 67.47%) and the KT (School 1 – 74.00%, School 3 – 70.71%) (Table 4).

3. 4. The Impact of Study Program on Students' Opinions and Attitudes Towards Didactical Aspects of the Hands-on Approach

Students' study programs were also related to differences in student opinions and attitudes towards the didactical aspects of the selected modules from visible spectroscopy (Table 9).

Statistically important differences at levels of significance 0.01 and 0.05 were found for the: (a) usefulness of

Table 8: Descriptive statistics for students' perception of specific knowledge and skills gained through hands-on approach and the statistical significance of differences between schools

Specific knowledge		N	Mean	Std. Deviation	One-way ANOVA F	Sig.
Colour of matter and absorption of light	SCHOOL 1	45	3 .22	1 .17		
	SCHOOL 2	28	2 .86	0 .85	4.40	0.006
	SCHOOL 3	25	3 .92	1 .22		
	SCHOOL 4	18	3 .06	1 .16		
	Total	116	3 .26	1 .16		
LED selection	SCHOOL 1	45	3 .27	1 .14		
	SCHOOL 2	28	3 .29	1 .08	4.02	0.009
	SCHOOL 3	25	4 .16	0 .99		
	SCHOOL 4	18	3 .33	1 .28		
	Total	116	3 .47	1 .16		
Role of the blank	SCHOOL 1	45	3 .58	1 .06		
	SCHOOL 2	28	3 .18	1 .02	3.81	0.012
	SCHOOL 3	25	4 .20	1 .08		
	SCHOOL 4	18	3 .67	1 .37		
	Total	116	3 .63	1 .15		
Transmittance/Absorbance relation	SCHOOL 1	45	3 .31	1 .08		
	SCHOOL 2	28	2 .86	0 .89	6.97	0.000
	SCHOOL 3	25	4 .08	0 .86		
	SCHOOL 4	18	3 .17	1 .10		
	Total	116	3 .34	1 .07		
Handling the instrument Spektra^{TM}	SCHOOL 1	45	3.89	1.03		
	SCHOOL 2	27	3.19	1.14	3.78	0.013
	SCHOOL 3	25	4.12	0.88		
	SCHOOL 4	18	3.50	1.47		
	Total	115	3.71	1.15		
Use of spectrometry for determination of concentration	SCHOOL 1	45	3.73	0.94		
	SCHOOL 2	27	3.19	0.74	3.60	0.016
	SCHOOL 3	25	4.00	1.08		
	SCHOOL 4	18	3.39	1.20		
	Total	115	3.61	1.01		

Table 9: Descriptive statistics for students' opinions and attitudes about didactical aspects of hands-on approach and its influence on their self-confidence for experimental work

		N	Mean	Std. Deviation	Std. Eror	One-way ANOVA F	Sig.
Usefulness of student's workbook	SCHOOL 1	45	3.93	1.07	0.16		
	SCHOOL 2	28	3.00	0.77	0.15	7.36	0.000
	SCHOOL 3	25	3.36	0.99	0.20		
	SCHOOL 4	18	2.83	1.25	0.29		
	Total	116	3.41	1.10	0.10		
Teacher's support	SCHOOL 1	45	3.80	1.12	0.17		
	SCHOOL 2	28	3.21	0.99	0.19	2.78	0.045
	SCHOOL 3	25	3.96	0.98	0.20		
	SCHOOL 4	18	3.39	1.29	0.30		
	Total	116	3.63	1.12	0.10		
Selection of experiments in each modules	SCHOOL 1	45	3.02	1.06	0.16		
	SCHOOL 2	28	2.96	0.74	0.14	4.00	0.010
	SCHOOL 3	25	3.84	1.11	0.22		
	SCHOOL 4	18	3.33	1.37	0.32		
	Total	116	3.23	1.10	0.10		
Group work	SCHOOL 1	45	3.98	0.97	0.14		
	SCHOOL 2	28	3.54	1.04	0.20	4.99	0.003
	SCHOOL 3	25	2.88	1.45	0.29		
	SCHOOL 4	18	3.44	1.25	0.29		
	Total	116	3.55	1.20	0.11		
Relaxing working climate	SCHOOL 1	45	4.20	0.97	0.14		
	SCHOOL 2	28	3.43	1.10	0.21	5.06	0.003
	SCHOOL 3	25	3.32	1.03	0.21		
	SCHOOL 4	18	3.50	1.34	0.32		
	Total	116	3.72	1.13	0.11		
Gained self confidence in doing experiments	SCHOOL 1	45	4.20	0.97	0.14		
	SCHOOL 2	28	3.43	1.10	0.21	6.24	0.001
	SCHOOL 3	25	3.32	1.03	0.21		
	SCHOOL 4	18	3.50	1.34	0.32		
	Total	116	3.72	1.13	0.11		

student's workbook (highest mean score by School 1); (b) teacher's support (highest mean score by School 3); (c3) selection of experiments in each module (highest mean score by School 3), (d) group work (highest mean score by School 1); (e) relaxing working climate (highest mean score by School 1); and (f) contribution to self-confidence (highest mean score by School 1). Students from School 1, on average, achieved the highest results in both experiential and knowledge tests, appreciation of student's workbook, and teacher support during completion of experiments, group work, relaxing climate, and influence of the approach on self-confidence, since the mean scores associated with these questions were all greater than 3.8 on a 5-point scale.

4. Conclusions – Regarding Research Questions

As for the first research question (How are students' motivational components (intrinsic, regulated, and controlled motivation) and their chemistry self-concept correlated with their experiential knowledge of visible spectrometry (knowledge gained through personal experiences with light and colour) and knowledge gained through a hands-on approach to visible spectrometry?), in contrast to most reported findings, our study did not find any statistically significant correlation among motivational components (intrinsic, regulated and controlled motivation) of the tested students, their subject-specific self-concept and their achievements in the experiential knowledge (EXT) and knowledge (KT) tests gained through the hands-on approach to visible spectrometry (Table 2).

We further investigated differences in motivational components among students enrolled in different technical study programs (Research Question 2). A one-way ANOVA analysis revealed a significant difference at the 0.05 level between students from different schools only for regulated motivation, (Table 3). Students who participated in the study were rather poorly intrinsically motivated, since the mean value of scores assigned to intrinsic motivation was 2.65 on a 5-point scale, (Table 3). We think that this might be the main reason why no correlations between motivational components and knowledge were found.

The study program (Research Question 3) did have an important impact on students' academic achievement. At the 0.01 level, statistically significant differences among schools were found for student academic achievement, (Table 4). Students in the biotechnology technical program (School 1) and laboratory biomedical technician program (School 3) achieved better results on both tests than did students in the food processing program (School 2) or the biotechnology general program (School 4). Alternatively, the greatest improvement in knowledge gained was noted for students in Schools 2 and 4, where statistically significant differences at the 0.01 and 0.05 levels in experiential knowledge and knowledge gained, respectively were found (Table 5). The differences in students' academic achievement in the KT might also be attributed to differences in background chemistry knowledge revealed by total general chemistry hours in the first and second year (Table 1). Students enrolled in the food processing program (School 2), with only 105 hours of background chemistry experience, obtained the lowest mean EXT and KT scores, however, students with the largest number of background chemistry hours (School 3) failed to achieve the highest KT results. Our results show that the total hours of background chemistry experience did not play an important role in students' academic achievement, as one might have assumed. This maybe due to other factors (e.g. teacher engagement, general school climate, and chemistry self-concept) that prevailed. Students from School 2 seemed to doubt that they were able to learn chemistry with understanding, since they assigned the lowest weight (3.05) to chemistry self-concept. In addition, their regulated motivation result was the lowest (3.06). Students from general and technical biotechnology programs had comparable prior chemistry experience, but their KT achievement differs; technical biotechnology program students (School 1) achieved, on average, better EXT (73.52%) and KT (74.00%) assessment results, than did students from the biotechnology general program (School 4, EXT 59.03%, KT 68.99%). Since students from both programs did not differ significantly in chemistry self-concept and motivational components, it is possible to conclude, that the study program's quality contributes to differences in students' academic achievement. Deeper insight into the structure of both knowledge tests (EXT and KT) from the perspective of the knowledge category assessed by specific test items revealed that through the hands-on approach to visible spectrometry, comprehension of the concepts supported was demonstrated at a satisfactory level (more than 60% of students solved these items correctly), while test items based on more demanding cognitive-level were solved satisfactorily by approximately 55% or less students (Graph 1). Some research findings indicated that the hands-on approach could enhance a series of competences among them, critical thinking, processing, and analyzing data and problem solving. However, we would need to conduct an extended study on a longitudinal basis to verify these findings.[43]

The quality of the study program is further reflected in students' perception of specific knowledge and skills gained through the hands-on approach to visible spectrometry and their evaluation of different didactical aspects of this approach (Research Questions 4 and 5). Students from School 1 and 3 who achieved high results in the knowledge test (KT) indicated that the hands-on approach to visible spectrometry enabled them to better understand concepts included in selected modules, since the mean values of the assigned weights to the selected concepts differ from 3.22 to 4.18 (Table 8). In evaluating different didactical aspects of the hands-on approach, the highest mean weight of 4.20 for students from School 1 was assigned to relaxing working climate and to contribution of the approach to increased confidence in doing experiments (Table 9). It is important to stress that these two aspects of the didactical approach were also evaluated by mean weights over 3.3 by other students. This could be regarded as an important finding of this study and, at the same time, a message to teachers, since autonomy-supportive teaching in a relaxing classroom atmosphere increases students' intrinsic motivation and subject specific self-concept.[33,34] Therefore, it is possible to infer, if teachers from technical schools more frequently offered students opportunities to experience a hands-on approach in learning and teaching chemistry-based and chemistry-related subjects, their students' chemistry self-concept and also intrinsic motivation would presumably gradually improve. Active student participation in learning processes could also contribute to their academic performance and mastery of higher-level cognitive skills.[43–45]

5. Acknowledgement

The authors wish to thank the Leonardo da Vinci funding agency, and especially all participating students, their teachers, and schools. Without their dedication and persistence, completion of this project would not have been possible.

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Povzetek

V članku so predstavljeni rezultati uvajanja pojmov s področja spektrometrije v vidnem področju z izkustvenim pristopom. V raziskavi je sodelovalo 118 dijakov in dijakinj štirih poklicnih šol, njihova povprečna starost je bila 18,6 let. Rezultati niso pokazali korelacij med motivacijskimi komponentami dijakov (intrinsičnimi, reguliranimi in kontroliranimi), njihovo kemijsko samopodobo in dosežki na pred-testu (pretekle izkušnje) in po-testu (s pristopom pridobljeno) znanje. Statistično pomembne razlike v znanju pa so se pokazale med dijaki v raziskavi sodelujočih šol; biotehnologija, tehnični program (Šola 1), živilska tehnologija (Šola 2), laboratorijska medicina (Šola 3) in biotehnologija, splošni program (Šola 4). Razlike v znanju so se odrazile tudi v odnosu dijakov do pridobljenega znanja in izraženih mnenjih o didaktičnih značilnostih izkustvenega pristopa. Vsi dijaki so, ne glede na program, kot zelo pozitivno ocenili sproščeno vzdušje pri izvajanju eksperimentov in prispevek izkustvenega pristopa k njihovi samozavesti pri izvajanju laboratorijskih aktivnosti.