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ASSESSMENT OF THE UNIVERSITY OF OSIJEK ENGINEERING STUDENTS' CONCEPTUAL UNDERSTANDING OF ELECTRICITY AND MAGNETISM

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Original scientific paper
The study of the conceptual understanding of electricity and magnetism was conducted with the engineering students at the University of Osijek. The Conceptual Survey of Electricity and Magnetism (CSEM), a recognized multiple choice test, was used to assess the students' conceptual understanding of electricity and magnetism and to diagnose difficulties they have in this domain. The test was administered to the first year undergraduate students of electrical engineering, computer engineering, civil engineering and food technology. The students from the Department of Physics were also included in the survey. The data analysis of the multiple-choice questions was performed by statistical methods of the classical test theory which determines the reliability and discrimination of the test as well as the relation of certain questions to the entire test. The CSEM results were compared with the published results of the American study and with the previously conducted testing in Croatia. Some students' misconceptions regarding difficulties in understanding certain concepts of electromagnetic induction and application of Newton‘s laws in the context of electromagnetism have been identified. The comparison of the engineering students' conceptual and procedural knowledge of electricity and magnetism has also been evaluated.

Keywords: *conceptual and procedural knowledge, CSEM test, electricity and magnetism, misconceptions*

Procjena konceptualnog razumijevanja elektriciteta i magnetizma kod studenata tehničkih fakulteta Sveučilišta u Osijeku

Izvorni znanstveni članak
Istraživanje konceptualnog razumijevanja elektriciteta i magnetizma provedeno je na populaciji studenta tehničkih fakulteta Sveučilišta u Osijeku. Kao dijagnostički instrument korišten je općepoznati američki CSEM (Conceptual Survey of Electricity and Magnetism) test višestrukog izbora pomoću kojeg se može provjeriti razumijevanje nekih temeljnih fizikalnih koncepata iz elektriciteta i magnetizma te dijagnosticirati poteškoće koje studenti imaju pri njihovom usvajanju. Razumijevanje ovih koncepata provjereno je na Sveučilištu u Osijeku kod studenata prvih godina elektrotehnike, računarstva, prehrambene tehnologije i građevinarstva podijeljenih u nekoliko skupina. Isto tako u istraživanju su sudjelovali studenti fizike Odjela za fiziku Sveučilišta u Osijeku. Dobiveni rezultati analizirani su statističkim postupcima u okviru klasične test-teorije kojima je određena pouzdanost i diskriminacija cjelokupnog testa kao i odnos pojedinih zadataka prema cjelokupnom testu. Rezultati su uspoređeni s rezultatima izvornog američkog istraživanja te s rezultatima ranije provedenih testiranja studenata u Hrvatskoj. Izračunati statistički parametri pokazuju da se test može primjenjivati kao dijagnostički alat za procjenu razumijevanja temeljnih fizikalnih koncepata u elektromagnetizmu. Identificirane su neke studentske pretkoncepcije povezane s poteškoćama u razumijevanju pojedinih koncepata unutar konceptualnog područja elektromagnetske indukcije te primjene Newtonovih zakona u kontekstu elektromagnetizma. Isto tako dana je analiza usporedbe konceptualnog i proceduralnog znanja studenata u području elektromagnetizma.

Ključne riječi: *CSEM test, elektricitet i magnetizam, konceptualno i proceduralno znanje, pretkoncepcije*

1 Introduction

Present changes in university education have increased the need to educate more diverse groups of students to be successful in science, technology, engineering and mathematics (STEM). According to the Criteria for Accrediting Engineering Programs (ABET) standards, engineering students need to become reflective thinkers and effective problem solvers [1]. Students are expected to have a deep understanding of mathematics and basic sciences, but also of engineering practice.

Recent studies have shown that students, due to lack of sufficient interest, under-preparedness and poor study skills do not choose science, mathematics and engineering courses for their majors. Therefore, there has been a growing interest in engineering education research to study cognitive aspects of learning with the emphasis on understanding and measuring engineering students' learning rather than teaching [2, 3].

In recent time, the STEM disciplines have increased their use of Concept Inventories (CIs) which are valuable and necessary diagnostic instruments to investigate the students' learning in science fields and instructional effects at a student, classroom, and/or instructional program level. Unlike typical assessments of student academic achievement, the CIs represent a unique form of multiple-choice assessment tests which tends to be highly focused on a small set of key concepts and understandings within a limited domain of academic content. Thus, the CIs in higher education science can provide a learning opportunity for students and professors alike [4].

In the last twenty-five years many studies of physics education have established that before taking the introductory physics course the students have many preconceived ideas about the physical systems in nature. These ideas differ from the accepted scientific ideas and are often called alternative conception or common sense science. The misconception is the term that will be used in this study to refer to alternative conception. The misconception is a concept or idea that is embraced prior to instruction and is inconsistent with the current scientific concept [5]. However, it is very difficult for students to "get rid of" their misconceptions which has a negative impact on their comprehension of scientific concepts of physical systems. The scientific explanation of the physical phenomena often differs from the intuitive ideas or existing conceptual structures. Thus, the effectiveness of introductory physics instruction is important to enhance students' attitudes regarding the understanding of scientific processes, such as the improvement of quantitative problem solving, improvement of laboratory skills, and improvement of reasoning skills.

Research on student conceptions in physics increased dramatically after 1985 and a wide array of innovations in physics instruction have subsequently utilized the CIs as independent methods of evaluation [6]. Nowadays, to assess students' achievement and conceptual understanding of various physics domains in both traditional (lectures) and advanced (interactive) instruction and at different levels of education, many CIs tests have been developed and applied. These multiple-choice tests include various physical areas such as kinematics (TUG-K test), force and motion (FCI test), DC-circuits (DIRECT test), waves (WCI test), electricity and magnetism (BEMA test, CSEM test) [7÷13]. These tests usually contain multiple-choice questions because in that way it is possible to compare various groups of students. The use of diagnostic multiple-choice questions has a long history in science education [14]. In general, science CIs contain between twenty and thirty-five questions. The question, also called an item, consists of both a stem and response options. The stem refers to the statement that precedes the choices, or response options, in a multiple-choice question. Response options are further sub-divided in the correct response and the incorrect response options. The incorrect response options are often called distracters (or incorrect answers). The design of the CIs goes to conceptualizing the nature of the situations to be presented and developing plausible distracters that represent a range of partially correct understandings to fully incorrect understandings and misconceptions.

Electricity and magnetism is seen as a central area of physics curricula at all levels of education: primary, secondary and university. However, it is one of the most difficult topics in teaching physics. Physics education research has shown that students have difficulties in understanding electricity and magnetism because of the abstract nature of the subject which is difficult to visualize and because the mathematical relationships can be complex (for example, the idea of the electric and magnetic field and electrostatic potential) [15]. Unlike the concepts of mechanics, the students' conceptual understanding of electricity and magnetism has been much less investigated because to develop a quality diagnostic instrument for assessment of understanding of these concepts is more demanding as compared to the assessment of the conceptual understanding of mechanics. Namely, electricity and magnetism is a much broader conceptual area and it also relies on understanding of other mechanics concepts such as force, motion and energy. In the domain of electricity and magnetism most students lack of understanding of the electromagnetic phenomena refer to no understanding of the concepts, but also the terminology, physical laws and relations. This question of (non) understanding the phenomena versus formalism (the formalism includes mathematical expressions of the concepts, laws and relations) is important for electricity and magnetism because the traditional instruction prefers formalism to the explanation of the phenomena. Therefore, in the assessment of conceptual understanding of electricity and magnetism there is a dilemma whether to focus on the understanding of the phenomena or on formalism.

One of the most common tests in the Physics Education Research (PER) community is the Conceptual Survey of Electricity and Magnetism (CSEM) [13]. The CSEM is designed to assess students' knowledge of electricity and magnetism including mathematical formalism in explaining the phenomena and the conceptual understanding of electricity and magnetism. The test can be used as both a pretest and posttest. A pretest is often administered at the beginning of a course, whereas a posttest can be given at the end of a course. In that way it is possible to assess the students' initial knowledge of electricity and magnetism and the effects of various teaching techniques, methods and approaches on students' knowledge and understanding in order to compare courses, curricula and instructional methods.

The study presents the application of the CSEM as a posttest for undergraduate and application oriented studies students of electrical and computer engineering at the Faculty of Electrical Engineering as well as for the students at the Department of Physics of the University in Osijek. The test was administered as a pretest to the students at the Faculty of Food Technology and the Faculty of Civil Engineering. The aim of the study was to assess the undergraduate engineering students' conceptual understanding of electricity and magnetism and to diagnose and identify some students' misconceptions connected with difficulties in understanding various conceptual domains of electricity and magnetism.

At the university level, the instruction of engineering students has been traditionally procedurally dominated, i.e. formulating and solving problems mathematically, although the instructors emphasize the importance of the conceptual base. Numerous studies have shown that many students lack correct conceptual understanding of science and engineering concepts, even after successful completion of courses in which these concepts are taught [16, 17]. In this study, the possible relations and correlations between students' conceptual and procedural understanding of electricity and magnetism have been investigated.

2 Background of the sample

The study was conducted at the end of the first (winter) and second (summer) semester academic year 2010/2011 involving 567 engineering students in the first year of the undergraduate study and of the application-oriented studies at the Faculty of Electrical Engineering and 27 physics students at the Department of Physics. As a control group, the undergraduate students in the first year of study at the Faculty of Civil Engineering and the Faculty of Food Technology were tested.

The students were classified into six groups:

(i) electrical engineering (FEE-EE , 88 students)
(ii) computer engineering (FEE-CE, 98 students))
(iii) application-oriented studies(FEE-AOS,184 students)
(iv) department of physics (DP-UNIOS, 27 students)
(v) food technology (FFT, 120 students)
(vi) civil engineering (FCE, 77 students) .

After a successful completion of the undergraduate study programme, the students are awarded a bachelor degree in electrical engineering, computer engineering, food technology or civil engineering. The students from the Department of Physics obtain the academic title

Bachelor of Physics. On the other hand, the Application Oriented Study programme lasts six semesters and after completing the study the students are awarded the title Bachelor of Engineering in their respective branches: Power Engineering, Automatic or Computer Engineering. Prior to the testing the undergraduate students and the students in Application Oriented Study at the Faculty of Electrical Engineering finish one semester of a calculus-based general physics course and mathematical courses which include linear algebra and differential calculus. In addition, they have also been instructed in Fundamentals in Electrical Engineering as one of the engineering courses. Calculus-based general physics courses (Physics 1, Physics) cover mechanics and heat and thermodynamics. Students acquire knowledge of the concepts and mathematically formulated laws of mechanics and thermodynamics, which enables them to understand mechanical and heat phenomena in nature and technology and to solve simple problems. The aim of the Fundamentals of Electrical Engineering 1 (FofEE1) course is to learn the basic laws in electrostatics and electrodynamics and to apply these concepts in solving various field problems. In particular, the content FofEE1 course includes properties of electrical and magnetic fields and electrostatic potential, static currents, capacitance, inductance and conductance. The courses Physics 1 at the undergraduate study and Physics at AOS include mechanics and heat whereas electricity and magnetism are partially taught in Physics 2 in the second semester of the undergraduate study. The first year students at the FFT and the FCE are not taught electricity and magnetism in the courses Technical Physics, Physics, respectively. Thus, these students were taken as control groups. Their knowledge and conceptual understanding of electricity and magnetism was based on methods of teaching physics during their secondary education.

The analysis of secondary schools types the students had completed before enrolling in university has shown that 51 % of the undergraduate students at FEE had finished grammar school (19 % natural sciences grammar school, 32 % other grammar schools) whereas 84 % of the students at AOS had finished vocational schools (36 % electrical engineering school). The DP-UNIOS and FCE students had mostly graduated from grammar schools, 85 % of the physics students (41 % natural sciences grammar school, 44 % other grammar schools) and 66 % of the civil engineering students (14 % natural sciences grammar schools, 42 % other grammar schools). On the other hand, 57,5 % of the food technology students had finished grammar schools (2,5 % natural sciences, 52 % other grammar schools) and 51 % vocational schools whereas 7,5 % of the students had not had Physics as a subject during their secondary education. The analysis of the students' achievements in Physics and Mathematics in secondary schools has shown that, on average, the FEE-EE and FEE-CE students were very successful: 23,3 % of them had had grade A (excellent), 34,2 % B (very good), 33,7 % C (good), and 6,8 % D (sufficient) and 2 % of the students did not respond. The FCE students had had the following grades: 20,3 % A (excellent), 36,7 % B (very good), 31,6 % C (good), 11,4 % D (sufficient), the FFT students: 8,5 % A (excellent), 27,8 % B (very good), 39,5 % C (good), 18,7 % D (sufficient), 5,5 % of the students did not respond, the FEE-AOS students: 2,6 % A (excellent), 13,6 % B (very good), 48,7 % C (good), 29,8 % D (sufficient) and 5,3 % of the students did not respond, and the DP-UNIOS students: 3,7 % A (excellent), 33,3 % B (very good), 33,3 % C (good), and 29,6 % D (sufficient). Gender distribution has shown that in the investigated sample of students from the University in Osijek, 75 % of them were male and 25 % female. In addition, 95 % of the students at the FEE were male and 5 % female. The male population has also prevailed at the DP-UNIOS (63 % male and 37 % female) and at the FCE (56 % male, 44 % female). On the other hand, the gender distribution at the FFT was as follows: 28 % male and 86 % female students.

3 Assessing diagnostic instrument

The conceptual knowledge was assessed by using the Conceptual Survey of Electricity and Magnetism (CSEM) test. The CSEM consists of 32 multiple-choice questions which are, quite unequally, divided by the authors, into 11 conceptual areas [13]. Some areas contain only a few questions whereas some questions cover several conceptual areas. This distribution of questions makes it more difficult to analyze the test results. However, 11 conceptual areas can be rearranged into six larger ones each of which containing the same number of questions [18]. The conceptual areas in the CSEM are presented in Tab. 1. Fig. 1 shows a sample question (question 27th).

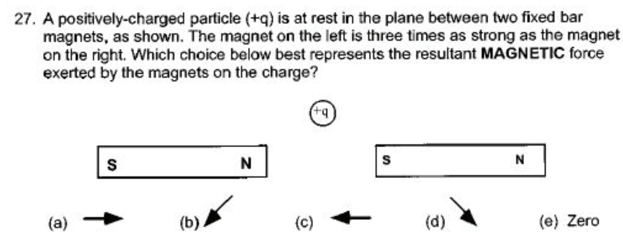

Figure 1 The example of the CSEM item (question 27th)

The test was administered to all groups of students at the Faculty of Electrical Engineering in Osijek at the end of the first semester, after the students had completed the FofEE1 course, (lectures, seminars and laboratory). The FFT and FCE students also took the test at the end of the first semester, but after the course on Technical Physics which included mechanics and heat, but not electricity and magnetism. The students of physics at the DP-UNIOS were tested, at the end of the second semester, after the completion of the mechanics and electromagnetism courses. Thus, the CSEM was a posttest for the FEE and DP-UNIOS students, whereas for FFT and FCE students it was a pretest. Before the test, the researcher who was present during the testing, explained the purpose and the importance of such testing. In addition, the students had also filled out the form supplying information on gender, secondary education and their prior achievements in physics and mathematics in terms of grade in the respective subject. The testing was anonymous, but each student was assigned a code in order to make it possible for them to check their results. In order to motivate the students to take the test seriously, points were earned and the results were taken into account when assessing their achievement in the calculus-based physics courses or in the FofEE1 course.

The allocated time was 60 minutes and the students were asked to avoid copying and random guessing and to try to give answers which reflected their personal opinion. They were also instructed to answer all questions as there were no negative points for wrong answers.

The results of the students from Josip Juraj Strossmayer University in Osijek were compared with the results of similar studies carried out with the undergraduate students at the Faculty of Science, University of Zagreb (FS UNIZG) and with a large number of introductory physics students at American universities [13, 18]. At FS UNIZG, 84 students at the end of the first year of study were involved (35 research oriented study students and 49 educational studies students). The introductory physics courses in the first year included mechanics as well as electricity and magnetism. In the USA, the CSEM was administered to more than 1000 students, enrolled in calculus-based and algebra-based physics courses, both as a pretest and posttest.

Table 1 Conceptual areas and question numbers that address each area of the CSEM test

Conceptual area	Question number	Summary of questions in conceptual area
The electric charge and force (*ECF*)	1, 2, 3, 5, 6, 8	The area is about the properties and interaction of electric charges. These questions test students' knowledge of charge distribution on conductors and insulators, the application of Coulomb's force law and the superposition principle for the electric force. The associated formalism requires vector addition and algebraic reasoning.
The electric field and force (*EFF*)	9, 12, 13, 14, 15	The area is concerned with the force caused by an electric field, the superposition of electric fields, and the effect of the induced charge on the electric field. The formalism includes vector addition and the interpretation of field lines.
Electric potential and energy (*EPE*)	11, 16, 17, 18,19, 20	The area tests students' understanding of the concept of electric potential energy and the relation between electric potential and other physical quantities such as electric field, work and electric force. The associated formalism involves the interpretation of equipotential lines.
The magnetic field and force (*MMF*)	21, 23, 25, 26, 28	The area refers to the motion of charged particles in a uniform magnetic field, the Lorentz's force, the magnetic field of a current carrying wire and loop, and the superposition of magnetic fields. The formalism includes vector addition, vector product, and the interpretation of field lines.
The electromagnetic induction (*EMI*)	29, 30, 31, 32	The area refers to understanding of induced voltage as a result of the change in magnetic flux and the motion of the straight conductor in a uniform magnetic field. The formalism includes vector product and graph interpretation.
The Newton's laws in an electromagnetic context (*NL* in *EM*)	4, 7, 10, 24, 27	The area is about the application of Newton's first law in the context of magnetic forces, Newton's second law in the context of the motion of a charged particle in a uniform electric field, and Newton's third law in the context of electric force between two unequal point charges, and the magnetic force between two current carrying wires. The questions require the understanding of some concepts of electricity and magnetism in addition to understanding of Newton's laws. The formalism includes a vector representation of forces.

Table 2 The overall results of the statistical analysis of the CSEM test

Statistical parameter	The possible range of values	The accepted values	FEE-EE (N=88)	FEE-CE (N=98)	FEE-AOS (N=184)	DP-UNIOS (N=27)	FFT (N=120)	FCE (N=77)
KR-20 test reliability index r_{test}	[0, 1]	≥ 0,7	0,84	0,75	0,83	0,85	–0,19	0,17
Ferguson' delta δ	[0, 1]	≥ 0,9	0,97	0,88	0,84	0,91	0,88	0,89
Point-biserial coefficient $\overline{r}_{\text{pbc}}$ (the average values)	[–1, 1]	≥ 0,2	0,40	0,32	0,37	0,40	0,15	0,19
Item difficulty index $\overline{p}$ (the average values)	[0, 1]	≥ 0,3	0,50	0,59	0,62	0,38	0,21	0,22
Item discrimination index $\overline{D}$ (the average values)	[–1, 1]	≥ 0,3	0,27	0,15	0,33	0,48	0,12	0,18

3.1 Statistical analysis of the CSEM data

As for any assessment instrument, it is important to analyze and monitor the functioning of an applied test. The students' CSEM scores are often used as the measure of students' conceptual understanding of electricity and magnetism. However, it is important to realize that the meaning of those scores depends strongly on the structure and functioning of the test as a whole, as well as on the functioning of each question (item). Therefore, the obtained CSEM results were analyzed using the classical test theory as one of the statistical methods for analyzing the multiple-choice questions. It assumes that the total score was made up of two components: a true score and a random error. The classical test theory provides different measures to evaluate multiple-choice tests and their items. Five measures used in this study are often used in science education research. This paper gives only a brief outline of the meaning of these measures. More detailed information about these measures can be found in Ding and Beichner [19, 20]. Three measures were for the *item analysis*: item difficulty indices (p, q), discrimination index (D), point biserial coefficient (r_{pbc}) and two were for the *test analysis*: Kuder-Richardson reliability index (r_{test}) and Ferguson's delta (δ). The aim of the statistical analysis is to examine the reliability and the discrimination of the CSEM. For a reliable test, similar outcomes are expected, if the test is administered twice (at different times), assuming the examinees' performance is stable and the testing conditions are the same. For discrimination test, the results can be used to clearly distinguish those who have a robust knowledge of the tested materials from those who do not. In this way the problematic questions can be identified.

The item difficulty index is a measure of the difficulty of a single test item. It is calculated by taking the ratio of the number of correct (p) or wrong (q) responses on the item to the total number of students taking the test. The range for the difficulty index p value is [0, 1], but the accepted values are $0,3 \leq p \leq 0,9$. However, it is more appropriate to subtract 0,5 ($q^* = q - 0,5$) from the difficulty index of each item, so that a medium difficulty is represented by zero. The positive difficulty indicates more difficult items, whereas negative values indicate less difficult items. In this way the re-scaled difficulties (q^*) can be obtained. The range of the re-scaled difficulty index is $-0,5 \leq q^* \leq 0,5$ [18]. The item discrimination index (D) is a measure of discriminatory power of each item in the test. It is used to differentiate between high-achieving and low-achieving students. The possible range for the item discrimination index D is [–1, 1]. Generally, an item is considered to provide good discrimination if $D \geq 0,3$. The point biserial coefficient (r_{pbc}), sometimes referred to as the reliability index for each item, is a measure of consistency of a single test item with the whole test. It reflects the correlation between students' scores on an individual item and their scores on the entire test. The point biserial coefficient has a possible range of [–1, 1]. If an item is highly positively correlated with the whole test, then the students with high total scores are more likely to answer the item correctly than the students with low total scores. On the other hand, a negative value indicates that the students with low overall scores were likely to get a particular item correct which indicates that the particular test item is probably defective. Therefore, a widely adopted criterion for measuring the "consistency" of a test item is $r_{\text{pbc}} \geq 0,2$. If the values of the point biserial coefficient are $0,20 \leq r_{\text{pbc}} \leq 0,39$ the item is good, very good if $0,40 \leq r_{\text{pbc}} \leq 0,59$ and if $r_{\text{pbc}} \geq 0,6$ it is an excellent item.

Kuder-Richardson reliability index is a measure of internal consistency of a whole test when test items are dichotomous (i.e., correct or incorrect answers) as in the CSEM. Higher correlations between individual items result in a higher Kuder-Richardson index, indicating higher reliability of the whole test. The range of the possible values for the KR-20 reliability index is [0,1] [21]. A widely used criterion for a reliable group measurement is $r_{\text{test}} \geq 0,7$ and tests, with $r_{\text{test}} \geq 0,8$, are reliable for individual measurement. In physics education, evaluation instruments are designed to be used to measure a large group of students, so if a certain physics test has a reliability index higher than 0,7, no one can safely claim it is a reliable test [20, 21].

Ferguson's delta (δ) is a measure of the discriminatory power of a test. It takes into account how broadly students' total scores are distributed over the possible range. Generally, the broader the total score distribution is, the better discriminatory power the test has [12]. The possible range of Ferguson's delta values is [0, 1]. If the test has Ferguson's delta $\delta \geq 0,9$, it is considered to offer good discrimination.

4 Results and discussion

The results of the *CSEM* test for all tested groups of engineering students at the University in Osijek in year 2010/2011 are given in Tab. 3. The data in this table present the statistical information about the obtained results (arithmetic mean, median, standard deviation σ, standard error of the mean $SE = \sigma / \sqrt{N}$, minimum and maximum score).

Table 3 The overall success on the *CSEM* of engineering students at the University of Osijek

Groups of students	Number of students	Test	(Average score) Arithmetic mean %	Median, %	Standard deviation, %	Standard error of the mean, %	Min – max, %
FEE-EE	88	posttest	50,5	50,0	19,3	2,1	12,5 ÷ 87,5
FEE-CE	98	posttest	59,3	62,5	10,8	1,1	15,6 ÷ 75,0
FEE-AOS	184	posttest	62,1	68,8	13,3	1,0	18,8 ÷ 78,1
DP-UNIOS	27	posttest	38,3	31,3	18,9	3,6	15,6 ÷ 65,6
FFT	120	pretest	21,0	18,8	6,3	0,6	6,3 ÷ 37,5
FCE	77	pretest	21,7	21,9	7,5	0,9	9,4 ÷ 40,6
Total	594		45,4	42,2	18,8	0,8	6,3 ÷ 87,5

The overall score of all tested students at the University of Osijek was 45,4 % which was in accordance with the achievement of the students of physics at the Faculty of Science in Zagreb (48 %) and the students from American universities (47 %). However, when comparing the CSEM posttest results, the average score of the students from the University of Osijek achieved 53 %, slightly better than the American and the physics students from the University of Zagreb. On the other hand, the food technology and civil engineering students achieved only 21 % in the CSEM pretest (21 % - FFT, 21,7 % - FCE), which was only slightly higher than the random choice limit (20 %). Such results were partially expected as the students were not familiar with either the electromagnetic phenomena or with the physical laws and relations. The students also lacked a deep understanding of fundamental concepts in mechanics taught in secondary schools and in the first semester in the physics courses. Nevertheless, the results of the FFT and FCE students who had finished the algebra-based physics courses were similar to the pretest results of the American students (25 % ÷ 31 %).

Distribution of the overall results per the *CSEM* conceptual areas for all tested students is shown in Fig. 2. The FEE and the DP-UNIOS physics students (66 % - FEE-CE 58 % - FEE-EE, 70 % - FEE-AOS, 46% - DP-UNIOS) were more successful in areas which included electricity (ECF, EFF, EFE) than those which referred to magnetism (MFF, EMI, NL in EM) (51 % - FEE-CE, 45 % -FEE-EE, 49 % - FEE-AOS, 29 % - DP-UNIOS). The worst results were achieved in the EMI conceptual area (45 % - FEE-CE, 37 % - FEE-EE, 43 % - FEE-AOS, 25 % - DP-UNIOS) which indicates lack of understanding of the induced voltage due to magnetic flux change as well as the formalism which includes vector product and graphic interpretation of a magnetic field. On the other hand, the FEE and the DP-UNIOS students have shown a good understanding of concepts in electricity (electric field and potential, but also the interpretation of equipotential and field lines) as the results in this area were the best (75 % - FEE-CE, 63 % - FEE-EE, 66 % - FEE-AOS, 49 % - DP-UNIOS).

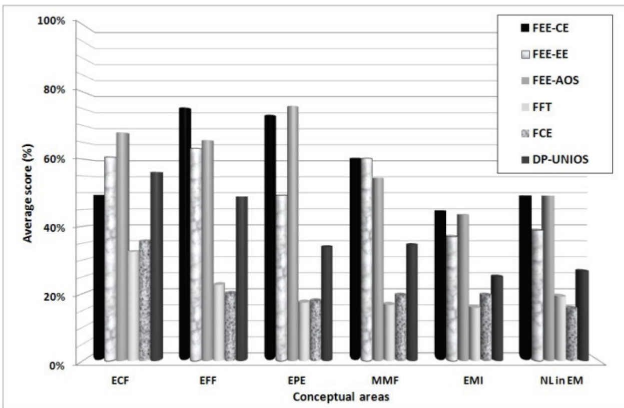

Figure 2 The distribution of the overall success per CSEM conceptual areas

The results of the statistical analysis, which are summarized in Tab. 2, indicate that the CSEM, administered as a posttest, is an adequate diagnostic instrument to assess the engineering students' at the FEE and the physics students' at the DP-UNIOS conceptual understanding of electricity and magnetism. Reliability and discrimination power of the CSEM as a posttest was confirmed by the acceptable average parameters values: r_{test} = 0,82, δ = 0,90. The calculated values of the r_{test} reliability parameters for all four tested groups students are higher than the limit value ($r_{\text{test}} \geq 0{,}7$) and are quite similar to the results of the posttest administered to the American students ($(r_{\text{test}})_{\text{USA}} \approx 0{,}75$) [13]. The FFT and FCE students' reliability parameter has been far from the limit value ($(r_{\text{test}})_{\text{FFT}} = -0{,}19$, $(r_{\text{test}})_{\text{FCE}} = 0{,}17$), which indicates that the students lack both inner and outer motivation to take such a test. However, even for these two groups of students the CSEM as a pretest has a good discrimination power because δ–Ferguson parameters have acceptable average values (δ_{FFT} = 0,88, δ_{FCE} = 0,89).

Comparison of the q^* re-scaled item difficulty indices per conceptual area of the CSEM test for Croatian and American students (Fig. 3a) indicates that for the FEE students most areas (four out of six) have negative average difficulty, i.e. there were more than 50 % correct answers in these areas. For the DP-UNIOS students, the Faculty of Science students and American students most areas (five out of six) have positive difficulties, i.e. less than 50 % correct answers in these areas.

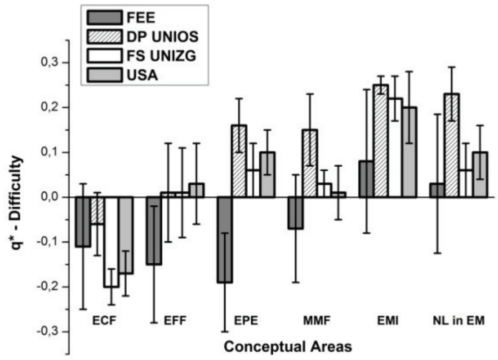

Figure 3a Comparison of the re-scaled item difficulty indices per conceptual areas of the CSEM as a posttest for Croatian and American students.

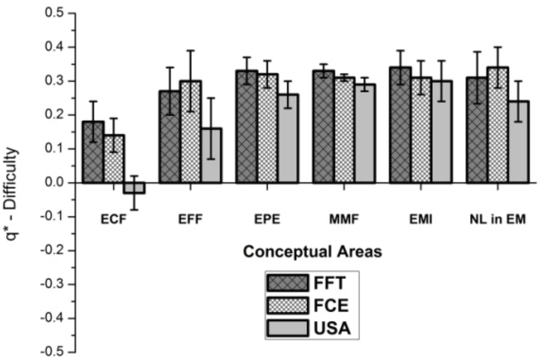

Figure 3b Comparison of the re-scaled item difficulty indices per conceptual areas of the CSEM as a pretest for Croatian and American students.

Distribution of average difficulties per conceptual areas for the FFT and FCE students, to which the CSEM was administered as a pretest, was very similar to the pretest results of the American students (Fig. 3b). In addition, average difficulties of the EFE, MFF and EMI areas were approximately $q^* \geq 0{,}3$ which indicated that in this multiple-choice test these students were choosing the answers randomly. This has been an interesting result because there were significant differences between the American and Croatian students which first of all referred to the size of the sample but also to different methods of physics instruction and use of textbooks and other teaching materials. The CSEM pretest results have also indicated that the students, during their secondary education, acquired very limited knowledge of electromagnetic phenomena. The students have shown certain understanding of the conceptual areas about properties and interaction of electrical charges, the application of Coulomb's law and the concepts of relation between electrical forces and fields but despite that they have found these areas quite difficult.

4.1 Engineering students misconceptions in electricity and magnetism

Fig. 4 shows the parameters of the statistical item analysis of each item in the CSEM conceptual areas for each group of engineering students at the University of Osijek. The calculated average values of the point biserial coefficients: $(r_{\text{pbc}})_{\text{FEE-EE}} = 0{,}40$, $(r_{\text{pbc}})_{\text{FEE-CE}} = 0{,}32$, $(r_{\text{pbc}})_{\text{FEE-AOS}} = 0{,}37$, $(r_{\text{pbc}})_{\text{DP}} = 0{,}40$ have confirmed a good correlation between individual items and the whole test with the FEE and DP-UNIOS students. Satisfactory correlation has been noted with the FCE students (r_{pbc} = 0,19) whereas for the FFT students the correlation has been unsatisfactory (r_{pbc} = 0,15). The average item discrimination index in the posttest for the undergraduate FEE students has been $\overline{D} = 0{,}39$ and includes the interval $-0{,}42 \le D \le 0{,}56$, for the FEE-AOS students the index has been $\overline{D} = 0{,}33$ with the interval $-0{,}46 \le D \le 0{,}90$, whereas for the DP-UNIOS students $\overline{D} = 0{,}48$ and $-0{,}29 \le D \le 1{,}0$ (Fig. 4a). For the FFT and FCE students the indices have had very low values ($-0{,}14 \le D_{\text{FFT}} \le 0{,}38$, $-0{,}05 \le D_{\text{FCE}} \le 0{,}53$) which indicate that these students have found almost every test item too difficult for them (Fig. 4b). The FEE students had significant difficulties with the application of Newton's laws in the domain of electricity and magnetism. Namely, the most difficult question (q^* = 0,45; 95 % incorrect answers) was about superposition of magnetic fields and the application of Newton's laws in description of electric charge motion in the constant magnetic field. This confirms the statement according to which the students have difficulties transferring the mechanics' concepts to other domains such as electricity and magnetism [15].

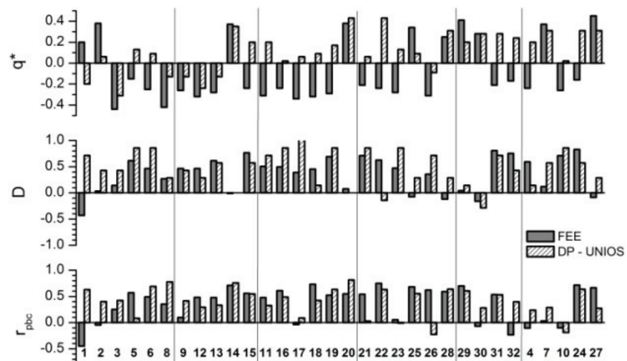

Figure 4a The parameters (the re-scaled difficulty index (q^*), the item discrimination index (D), the point biserial coefficient (r_{pbc})) of the statistical item analysis of each item in the CSEM conceptual areas of the CSEM as a posttest for the FEE and the DP-UINOS students.

The statistical analysis of the CSEM test items has shown some problematic items and the conceptual areas which have been more difficult for the engineering students.

All tested students, in both pretest and posttest, have achieved the best results in the first CSEM conceptual area (ECF) with the lowest re-scaled difficulty indices, i.e. the students had the most correct answers (61 % correct answers for FEE students; 56 % for DP students; 32 % for FFT and 36 % for FCE students). In this area, the students have had accurate conceptions in questions relating to electric field and force superposition, as well as straightforward application of Coulomb's law. Therefore, questions 3rd and 8th, are the easiest of all, with the highest percentages of correct answers in both pretest and posttest (93 % - FEE, 80 % - DP, 44 % - FFT, 42 % - FCE). Most of the problems in ECF conceptual area occurred because students do not understand how electric charges are distributed on conductors and insulators. In the question about conductors a majority of the students on the posttest distribute the charges over both the inner and outer surfaces of the metal sphere (65 % - FEE). Only the students of physics (70 % - DP) gave a correct answer that the charge is distributed over the outer surface of the metal sphere. In the question about the charge distribution on an insulator it could be noted that the students' answers distribution is in fact random, which would be expected if students did not have any firm initial ideas. The majority of students (55 % posttest students, 78 % pretest students) had the incorrect conception that there would be no excess charge left on the insulated hollow sphere after the charge was placed on the sphere. Therefore, it could be concluded that a substantial number of students seem not to be able to distinguish between conductors and insulators or fully understand what happens to the charge.

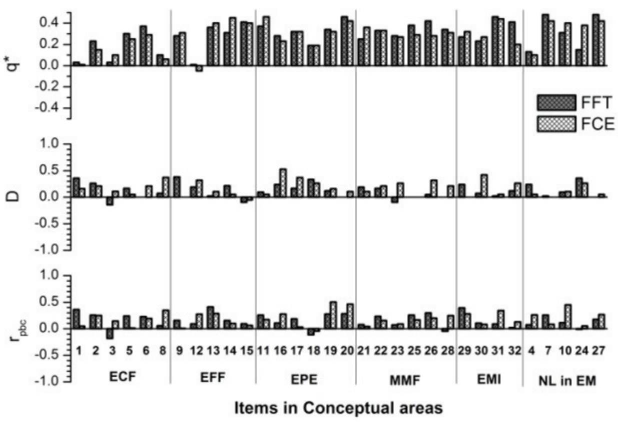

Figure 4b The parameters (the re-scaled difficulty index (q^*), the item discrimination index (D), the point biserial coefficient (r_{pbc})) of the statistical item analysis of each item in the CSEM conceptual areas of the CSEM as a pretest for the FFT and the CE students at the University of Osijek

The second (EFF) conceptual area was also one of the easiest CSEM areas for the engineering students (65 %, 49 %, 23 % and 20 % correct answers for FEE, DP, FFT and FCE students, respectively). In this area, the engineering students held accurate conceptions on the question about the uniform electric field and field superposition (76 % - FEE, 63 % - DP), as well as about the effect of the induced charge on the electric field (82 % - FEE, 74 % - DP, 49 % - FFT, 55 % - FCE). However, the students' results in this area have shown that the students' knowledge of the shielding effect of conductors seems rather weak. In Fig. 4a, there is a significant difference in re-scaled difficulties of questions 13th and 14th, which assess the students' knowledge of the effect of induced charge on the electric field. For question 13th, a majority of the students gave the correct answer (78 % of FEE and 63 % of DP students). On the other hand, question 14th is one of the most difficult questions for the engineering students at the posttest (13 % of FEE and 15 % of DP students). Question 13th gives a description of Faraday's cage which is often taught in physics and basic electrical engineering courses. However, question 14th adds the charge inside the cage which seems to be a problem for most of the students. These results have shown that the induced charge is quite a big conceptual problem. Besides, in the posttest about 40 % of the engineering students answered that both charges experience the same net force directed away from each other, which would indicate a misuse of Newton's third law.

In the posttest, the third (EPE) conceptual area is obviously the easiest CSEM area for the engineering students (69 % correct answers for FEE students) and a rather difficult one for students of physics (34 % correct answers for DP students) (Fig. 4a). The results in this conceptual area indicated that the engineering students had good knowledge of the abstract concept of the electric potential and the interpretation of the equipotential lines. Most of the problems in this area occurred in question 20th about the determination of the magnitude and the direction of the electric force from a change in potential (12 % correct answers for FEE students, 7 % for DP, 4 % for FFT and 8 % for FCE students). The students seem to be confused about whether an increase or decrease in potential determines direction. These results have shown the students' misconception that large distances between equipotential lines would be associated with a stronger field.

For the engineering students the fourth (MFF) conceptual area was the easiest one in the CSEM posttest which includes the domain of magnetism, (57 % correct answers for FEE students) and rather difficult for the students of physics (35 % correct answers) (Fig. 4a). The results in this area have shown that students correctly used the right-hand rule for determining the direction of the magnetic field relative to the electric current, but failed to resolve what happens to the charge when it is placed in the magnetic field. The most problematic question in this area was the one where students needed to determine the magnitude of the force exerted by the field on the moving charge in the different directions (16 %, 41 %, 12 % and 21 % of correct answers for FEE, DP, FFT and FCE students respectively). Most of the incorrect answers have indicated a misuse of the mechanical work concept.

The most difficult conceptual area in the CSEM test, in which the engineering students and the students of physics had the most of misconceptions, was the fifth (EMI) area about Faraday's law and the magnetic induction (45 %, 25 %, 16 % and 19 % of correct answers for FEE, DP, FFT and FCE students respectively). The results in this area have indicated that the students have difficulties with using the concept of the magnetic flux in the reasoning about the electromagnetic induction. In this area, all tested engineering students mostly had problems answering the question which assesses the understanding of the induced charge due to the magnetic flux (9 %, 30 %, 23 % and 18 % of correct answers for FEE, DP, FFT and FCE students, respectively). It can be noted that the most incorrect answers chosen by the students were those that do not include the change of the magnetic flux due to the change of the loop surface. Therefore, it seems that most of the students have recognized that only the motion from either the loop or the magnet is necessary to create an induced current. Besides, the majority of the incorrect answers indicated that students did not recognize the collapsing loop as changing of the magnetic flux or the rotating loops as not changing of the magnetic flux.

The overall students' scores in this study have shown that the second most difficult area in CSEM includes the application of Newton's laws in the domain of electricity and magnetism (NL in EM) (47%, 27%, 19% and 16% of correct answers for FEE, DP, FFT and FCE students, respectively). Although the questions in this area do not require any mathematical formalism and students should be familiar with Newton's laws from mechanics, the analysis of the students' choices of incorrect answers and the comparison of the difficulties of questions that assess the same concepts from electricity and magnetism without Newton's laws can be concluded that the problems in this area arise from the insufficient understanding of Newton's laws. One of the most problematic questions was the one about the determination of the magnitude and direction of the electric force between two electric charges (13 %, 19 %, 2 % and 8 % of correct answers for FEE, DP, FFT and FCE students respectively). More than 66 % posttest students answered that question incorrectly. The answers indicated that the majority of students consider that the magnitude and direction of the force determined by the magnitude of the electric charge and that they did not use the Newton's third law.

4.2 Comparison of the engineering students' conceptual and procedural knowledge of electricity and magnetism

The engineering students' procedural knowledge in electricity and magnetism was evaluated by assessing their performance in the final exam of the Fundamentals of Electrical Engineering 1 course (FofEE1). The final exam consisted of five problem-solving exercises similar to homework exercises which required the ability to identify and formulate the problem. The conceptual knowledge was measured by using the CSEM as a posttest. To compare students' conceptual and procedural performance a scatter plot was constructed for the data. The graph area was divided into four quadrants (numbered anti-clockwise beginning with the top right quadrant). The vertical and horizontal axes were split at the corresponding median value of the CSEM posttest and the FofEE1 final exam for all tested students (Fig. 5). The relation between conceptual and procedural knowledge was evaluated with the Pearson product-moment correlation coefficient.

The FEE-EE students' procedural and conceptual knowledge was compared. The average CSEM posttest score for this sample was $50{,}6\,\% \pm 19{,}4\,\%$ (standard error 2,1 %, median 50 %) and the average final exam score $57{,}6\,\% \pm 12{,}5\,\%$ (standard error 1,3 %, median 59,5 %).

For the total of 87 pair values (FofEE1, CSEM posttest) from Fig. 5, Pearson correlation coefficient between conceptual and procedural performance was r = 0,35. This value is positive and statistically significant which is shown by the test with Kendall's variable ($t=\frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$ = 3,458 > t_c = 1,989; t_c is a limiting theoretical value of the Student's variable for the significance level of 0,05 and (n – 2) = 85 degrees of freedom).

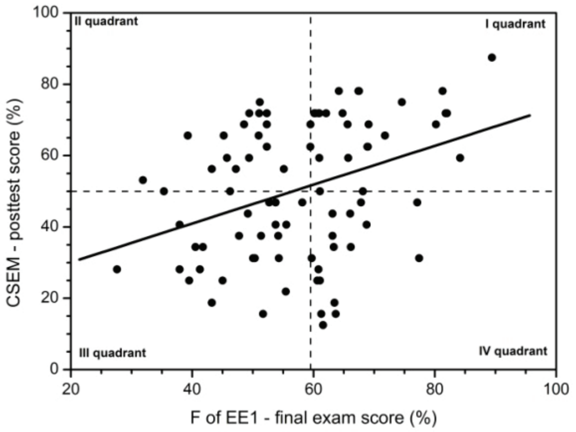

Figure 5 Comparison of the CSEM posttest scores with the scores of the undergraduate FEE-EE students in the FofEE1 final exam

The first quadrant, in Fig. 5, contains the students who performed well both conceptually and procedurally. More than one third of the students (32 %) were in this group. Approximately equal number of students (29 %) was in quadrant 3, which means that they performed poorly in both aspects. The second quadrant contains the students who performed well conceptually, but poorly procedurally, and the fourth quadrant contains students performing well procedurally, but not conceptually. It is interesting to note that equal number of students (19,5 %) was conceptually strong and procedurally weak as well as procedurally strong and conceptually weak.

The results have indicated that there is a relation between conceptual and procedural knowledge of the electrical engineering students in electricity and magnetism. This study partially supports the simultaneous interaction approach which considers the conceptual knowledge as necessary and sufficient for correct use of procedure [22, 23]. As seen in Fig. 5, 19,5 % of the students had the conceptual knowledge but did not succeed in the final exam. On the other hand, 19,5 % of the students lacked conceptual knowledge but were proficient in procedures and problem-solving. Thus, the results have revealed, that in the context of electricity and magnetism, it is possible to have conceptual knowledge without considerable procedural skills, but a reverse situation is also quite possible.

Because students' exam preparation has been characterized by memorizing equations and formulas, many students have been able to apply the appropriate formula, but lack understanding of the basic principles. In that case the success depends on whether students remember the correct formula for the problem and calculate it correctly. Besides, in the FofEE1 course many engineering students had problems with the required mathematical formalism including vector algebra and differential calculus regardless of their conceptual knowledge in electricity and magnetism.

These results suggest that some general knowledge of the basic concepts and relations is needed in order to successfully solve complex problems. The conceptual knowledge forms the basis for learning new procedures but once acquired, the procedures develop independently. Nevertheless, developing students' procedural skill with complex problem exercises during the course does not enhance students' conceptual knowledge significantly.

5 Conclusion

The conducted assessment of the undergraduate students' conceptual understanding of electricity and magnetism with the CSEM test has shown that the electrical and computer engineering students, who were taught the physical basics of electrical engineering, have acquired a good knowledge of the basic concepts of electricity and magnetism. The pretest achievement of the FFT students and FCE students is very low which could indicate difficulties in the understanding of electricity and magnetism concepts during their secondary education, but also the lack of both inner and outer motivation to take such a test. The statistical analysis results have determined that the CSEM test is the reliable test with the adequate discriminatory power and it can be administered as a diagnostic tool for assessment of the engineering students' understanding of the fundamental physical concepts in electricity and magnetism. In spite of the significant differences in teaching these physical concepts, a total achievement of undergraduate engineering students at the University of Osijek is in accordance with the results of both the original American study and the previously conducted testing of Croatian students.

The identified difficulties the students have with certain conceptual areas confirm the students' misconceptions that the concepts from one area could not be applied in some other physics domain. Therefore, in physics instructions more emphasis should be put on the connection between various physics domains and on the transfer of ideas between them.

The noted relation between conceptual and procedural knowledge by learning electromagnetism indicates the need to develop and introduce new instructional practices for improving students' conceptual understanding during introductory engineering courses.

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