

Project-Based Collaborative Learning of Electrical Engineering Master Students

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Abstract—The paper outlines a project-based collaborative learning methodology developed for graduate courses on Electrical Drives and Power Electronics in Tallinn University of Technology. An underlying principle of the described environment is the coursework arrangement directed to designing optimal application-specific drives with power electronic converters based on the active learning approach. The role of advanced computer-aided design tools is also identified and shown. To illustrate the effectiveness of this method, the industry-relevant course projects performed in the curriculum are presented in detail. An important result found is that all students acquired knowledge and skills to design more complex and sophisticated electromechanical systems.

Keywords—active learning; collaborative learning; project-based learning; electrical drive; power electronics

I. INTRODUCTION

As shown in [1], [2], [3], the traditional methods of teaching encourage a *surface approach* to learning, where students try to follow the routine solution procedures and match patterns rather than follow a *deep approach* where students develop a conceptual understanding of how the study system operates. Focus in the surface approach is on the ability to repeat what has been read without necessarily understanding it. Students' learning habits concentrating almost exclusively on exams, lead eventually to an overload, which in turn tends to result in a low level of knowledge. This effect is certainly causing students' stress and missing motivation. Therefore, traditional teaching appears to be ineffective in generating student enthusiasm and passion for learning. In this case, students may not be able to achieve the required goals to the full, or may be slow to reach their full creative talent and engineering potential.

Meanwhile, engineering companies require an aptitude for collaborative work, team and task management, concept synthesis, and decision-making from the graduates, thus promoting creation of a new environment for learning, which would provide all of these job-related skills. The main objectives are to provide high-quality teaching in terms of content in order to motivate students to learn additional skills not directly related to a speciality, however, considered very valuable in the professional working environment.

Contemporary changes in the business area, responses of companies to these changes and the available technologies pose

a number of challenges to the present and future engineers, as well as to the educational institutions, including

- collaborative work in the cross-functional, multidisciplinary, multinational, geographically dispersed teams
- creative work with a global customer base through developing communication skills with regular application, transfer and improvement of engineering knowledge

The Bologna meeting of 1999 set the convergence of all the national university programs of the European partners on a path towards a common frame. The main recommendations of that meeting concern the equivalent degrees implementable in more specific subjects and areas of shorter duration. A practical approach to teaching becomes more important in technological degrees, where students graduate and search for jobs in fast evolving companies.

As learning is a cognitive process, knowledge has to be constructed in the mind of the learner, in his/her efforts and activities. Learners can develop complex reasoning skills effectively when actively engaged in the material they are studying. They build meaning when reading, writing and discussing. Learning is aided by conversation that seeks to describe and clarify the ideas of the learners. Clarifying of understanding requires that students be provided opportunities to articulate their ideas, to test those ideas through experimentation and discussion, and to consider the connections between them.

From this viewpoint, an *active learning* strategy involving project-based learning and collaborative learning seems prospective [4], [5], [6].

Project-based learning, called also *learning by doing*, is a student-centered strategy that fosters initiative and focuses a student on authentic real-world open projects that can increase motivation for the majority of students and enhance their education [7], [8], [9], [10], [11], [12]. One aim of this approach is to organize the courses so that the students would be motivated to study.

Collaborative learning, called also *team-based learning*, is an educational method where students work in small self-directed teams to define, carry out and reflect upon a research task, which can often be a real-life problem [13], [14], [15],

[16], [17], [18]. The tutor acts here as a facilitator and resource person who they can meet for advice or guidance. This approach emphasizes cooperation and creating team learning and developing culture and makes it possible to include and use various scientific perspectives and methods of learning, research and development in operation and action.

To develop a new curriculum in Tallinn University of Technology, an experience of the partner institutions was used. Particular attention was paid to the 25-year experience of project-organized undergraduate education based on a unique pedagogic model of teaching gained at Aalborg University. In this method, a large part of semester teaching and student work revolves around the complex real-life problems or issues that the students consider and try to resolve while working together in groups [3]. Similarly, the curriculum structure proposed in [7] consists of eight courses: four theoretical courses and four project-based courses (including a compulsory master's thesis). In the project-based courses, the students working together in groups develop multidisciplinary systems, which become progressively more complex. An important result is that all students have developed effective systems, while considering that the results are worth the effort invested.

The following sections of the paper analyze the benefits and restrictions of the active project-based collaborative learning techniques based on their implementation experience in the master study program of Tallinn University of Technology. The description of each method is followed by the recommendations concerning possible ways of their use in electrical engineering education.

II. DESIGN OBJECTIVES

One example of active learning is the system built by the authors to study the disciplines included in the electrical engineering curriculum. The Advanced Course of Electrical Drives (AAV0040) and the Advanced Course of Power Electronics (AAV0050) are the master study optional courses provided in the Faculty Handbook. Course duration is 16 weeks, consisting of 3 contact hours per week and at least three hours of weekly independent work.

An electric drive is an electromechanical system that provides controlled inductive conversion of electrical energy into mechanical motion. It consists of mechanical transmission, an electric motor, an electronic power converter, and an informational controller. The power of supply lines is transformed into motor supply energy by the power electronic converter. Then, the motor converts it into electromagnetic energy, which in turn is transmuted into a shaft's mechanical energy. The controller forms the input references using information of the set-points, outputs, and disturbances. The engineering goal is to build an effective system using the components proposed by many world companies. Effective assembling of electric drives can solve the problems owing to rather complicated algorithms. Here, the mechanical, electrical, electronic, and power engineering problems are encountered in close integration.

The procedures of a motor drive and power electronic converter design involve a number of complex problems. Some of them are

- timing calculation and the mechanism travel diagram construction
- computation of mechanical forces and the torque/power patterns synthesis
- gear and motor dimensioning and selection
- the optimum motor-gear set choice and checking
- power electronic converter dimensioning and selection or design of the new one
- building the motor drive and power converter wiring diagrams
- development of controllers for the multi-loop control and adjustment
- the process simulation along with the analysis of the steady-state diagrams and transients
- economic considerations and efficiency evaluation of the project
- report generation, presentation and defense of the obtained results

Today, two ways of the drive development are used in the designers' community [19].

The first of them starts from the selection of a manufacturer; further, the manufacturer design technology and recommendations are used. For computation and equipment selection, the leading world companies have developed their specific technologies. Examples are the guidelines and software of Siemens, Omron, Sew Eurodrive, Maxon Motors, Mitsubishi Electric, etc. Such an approach is common for the majority of firms that carry out project design and have rich experience in acceptance of the decisions based on extensive computer data sources, making up numerous catalogue archives and "absorbing" their contents and structures.

The main drawback of the approach is the restriction of the design technology by the vendor company selected as a preferable manufacturer. Data limitations deprive a designer of an optimum way in the project. It is especially sensitive in the first project stage when the most responsible decisions are taken. Different manufacturers have worked out hundreds of databases and soft tools that provide most of the stages described above. All of these data sheets use different languages and operation systems. They have multiple structures, data types, data fields, keys, names, and inter-sheet connections. Not all required data are published; occasionally the knowhow of manufacturers may be concealed from the user. It is frequent practice that the provided information carries an advertising style, unnecessary for design purposes. Some data are published in the Internet; other information is accessible through printed materials and journals.

The second approach was proposed first in [20], [21] and then developed by further research into a computer-aided design system. As different from the companies, which manufacture and propagate their production, the proposed approach is addressed to the overall equipment selection, tuning, and optimization process independent of company

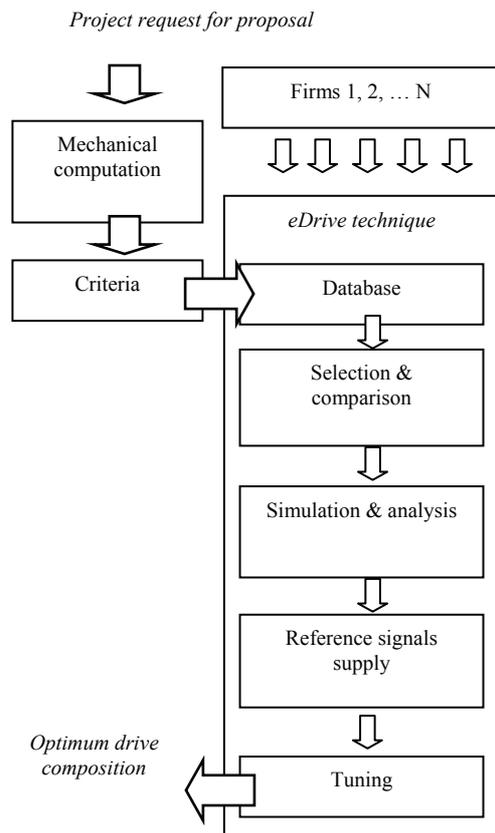


Figure 1. Project mastering structure

interests (Fig. 1). Using a search technique, the system transfers multiple data from a variety of databases into the uniform *eDrive* database (Fig. 2) with the specific data management system, which provides the search and updating of the data using the open-access corporative databases. The design process starts from the load computation using the project developers' own experience and methods. Further, a designer selects a group of gear types from different companies using the results of the load calculation. Through these gears, the forces and mechanism speed found before are converted to the equivalent values on the motor shaft. Then, the particular motor type that matches each gear type is to be selected based

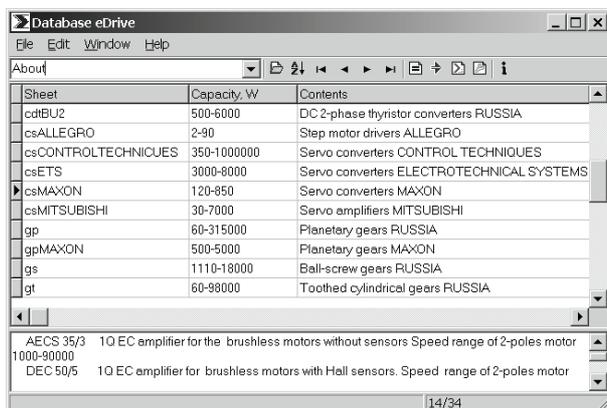


Figure 2. Database window

on the converted forces and speed. Thus, a set of possible drive variants is generated. Once the equipment framework is found, the new problem appears – which of the suitable motor-gear combinations is optimum? To find a solution, a designer can form appropriate criteria and sort them. It may be a criterion of maximum accuracy or speed, minimum weight, power, or inertia, highest rigidity, etc. Thus, the whole scale of the electromechanical and electronic properties is collected, from which the choice is done based on judgments about preferences of that or another criterion. Then, simulation of the open-loop system is done using the standard or the original simulation software. On the next stage, the power electronic converter equipped with a control system, which includes some regulators and sensors is designed or selected. Their transfer functions, gains, factors, and time constants are calculated to meet the standard settings. Then, the closed-loop system testing is carried out on the model and its optimization is executed, if necessary. This approach is more suitable for the educational targets thanks to its universality.

The learning outcomes for the multiple subjects in the master training program were listed by the researchers and industry agents. Senior engineers from various industries were contacted for their ideas regarding suitable industry relevant projects for the master students. Following a series of industry meetings and feedbacks, suitable topics were specified. The modules were designed, built and tested by the researchers. Then the specification sheets were handed to the students at course start. The projects are designed in a modular fashion, so that any independent module can be completed during the course that the student has enrolled in. The independent modules are assessed by the instructors teaching the course.

The master students are expected to design, build and test various modules as specified in the projects within a period of some months. In some projects, the students work individually, in other they are joined in groups of four while working on the project. They have to use the theoretical knowledge of Electrical Drives and Power Electronics as well and Computing Engineering, Mechanics, Automatics, etc. gained during their bachelor and master study. On completion of the project, students' learning experience and learning outcomes will be used to prepare their master's theses. The students' practical skills are assessed while working on the project, and their theoretical knowledge is graded on a written exam after the project completion.

III. PROJECT-BASED LEARNING

The main aims of an educational project are

- to set interactions and collaborations between teachers, students and industry partners
- to develop and sustain students' interest in engineering courses
- to satisfy industry demands, strengthen industry links and improve employability rate in industry
- to utilize effectively the teaching time for various courses in the curriculum

In accordance with the active learning principles stated above, it is not sufficient just to learn about professional and other issues and pass exams. The techniques need to be used in real situations by the master students and graduates. For the project-based approach, it is extremely important to emphasize the connections between different aspects, to encourage a broad-based system view and to illustrate the practical, technological and human constraints of solving the real-world problems.

The theoretical component deals with the formal theory of electric drives and power electronics. Today these theories have reached a degree of complexity that can only be managed by a lecturer. Moreover, a theoretical study does not always have to be passed before taking the practical assignments. To one part of students, it is more beneficial to acquire theoretical knowledge first, but to the other it is more reasonable to pass practice beforehand because this can provide a good basis for building the theory, thus helping students to understand some of the theoretical concepts. Consequently, multiple educational trajectories may be built that depend on student abilities and course contents and differences in the ratio of lecturing, practical and assessment classes are possible.

In our study, within the framework of the course, each student was required to design and develop, build, and test separately the personal drive unit equipped with a power electronic converter. The types of gears, motors, and power converters for the particular design problems had to meet the demands set by an instructor. To support learning, a series of problem exploration were proposed. One set of design problem examples is given in Table 1.

TABLE 1. PARAMETERS OF THE DRIVES DESIGNED

| Loading mechanism | Drive composition* | Mass m, kg | Speed v, m/s | Acceleration a, m/s ² | Path Δl, m | Cycle T, s |
|-------------------|--------------------|------------|--------------|----------------------------------|------------|------------|
| Support | gs-ms-c-φ | 1500 | 0.1 | 0.2 | 3 | 35 |
| | gs-ma-c-ω | 1250 | 0.15 | 0.3 | 2 | 15 |
| | gs-md-ct-φ | 1000 | 0.2 | 0.4 | 1 | 7 |
| Hoist | gp-ms-c-ω | 300 | – | – | 1 | 6 |
| | gw-ma-c-ω | 400 | – | 2.0 | 2 | 8 |
| | gt-md-ct-φ | 500 | – | – | 3 | 9 |
| Truck | gw-ms-c-ω | 3000 | 0.6 | – | – | – |
| | gt-ma-c-ω | 2500 | 0.5 | 1.0 | – | – |
| | gp-md-c-φ | 2000 | 0.4 | – | – | – |
| Conveyor | gp-md-ct-ω | 250 | 0.7 | – | – | – |
| | gt-ma-c-ω | 230 | 0.5 | 0.3 | – | – |
| | gw-ms-c-φ | 210 | 0.3 | – | – | – |
| Roll-table | gp-ms-c-ω | 500 | 0.9 | – | – | – |
| | gp-ma-c-ω | 1100 | 0.5 | 0.3 | – | – |
| | gw-md-c-φ | 5000 | 0.4 | – | – | – |
| Rotary table | gw-ms-c-φ | 300 | – | – | – | 10 |
| | gp-ma-c-ω | 250 | – | – | – | 8 |
| | gp-md-c2-φ | 200 | – | – | – | 9 |
| Crane | gp-ms-c-ω | 100 | 0.2 | – | 0.5 | 10 |
| | gw-ma-c-ω | 150 | 0.3 | 1.0 | 0.8 | 8 |
| | gt-md-ct-φ | 200 | 0.4 | – | 1.0 | 6 |

Here, the required drive compositions include multiple variants of gears: gt – spur, gp – planetary, gs – ball screw, gw – worm; motor drive types: ma – asynchronous, ms – synchronous servo drive, md – direct current; converters: c – transistor, ct – thyristor; control systems: φ – with speed and path feedbacks, ω – with current and speed feedbacks.

The final design report usually includes the following results:

- request for proposal with the individual input data
- timing calculation and the mechanism travel diagram
- mechanism's forces calculation and torque/power patterns
- optimum motor-gear set selection and checking
- power electronic converter dimensioning and selection or design
- data and simulation results with transients of an open-ended system
- block diagram of the control system
- controller development and tuning
- data and simulation results with transients of a close-loop system;
- conclusion of the project summary
- appendix 1 with an operation diagram of the thyristor phase modulation or the transistor 2-phase block or 3-phase pulse-width modulation
- appendix 2 with a wiring diagram with power circuit and drive specification

To implement project-based learning, the traditional style of lectures was changed so that the behavior analysis would replace partially the formal explanation of the theory within limits. Accordingly, if necessary, practice and lab work may precede lectures; moreover, new kinds of study may appear. In the lectures, problem scenarios are presented to the students before any relevant theory or practice is given. The open problems are framed by the teacher in accordance with the topics in the syllabus and a lecturer acts as a contractor. He/She asks the students (acting as subcontractors) to design and implement a fully functional motor drive or electronic converter that covers most of the topics reviewed in the theory lessons. The first classes are spent creating a systematic design of the final product – the specifications and main functions are described, and a functional block diagram is conceived. This policy means that students find the explanation of systems and ideas to be useful because they can see the target application. In addition, the start-to-finish design, from the block diagram until the final implemented system, helps the students in the task of determining, solving and grasping the problems. Another benefit is that the students must pay particular attention in the classes in order to complete the proposed prototype. During the next lessons, the lecturer reviews the designs and products and advises the students about the possible errors or mistakes. Therefore, the teacher is responsible for ensuring that each student's design is correct and that the final prototype is a working unit. Finally, he/she also acts as a vendor as the final prototype is usually implemented on the prototype boards.

The specially prepared textbook [22] and its web release contain sections supported project-based learning. Some of the

sections are intended to complement the lectures for beginners and for advanced learners, summarizing basic terms and conditions as well as the topical mathematical bases of the course. Other sections explain the broad self-learning part of the course. Calculation examples, experimental and assessment problems of the course are also provided. The multiple links connect the textbook with analogous and supplemental assignments in the field. The properly structured index and the reference list serve as the powerful navigation tool.

In addition, the assessment strategy was redefined and reformulated for project-based learning and additional evaluation methods were proposed to stimulate the learner. Particularly, the new assessment procedure invokes to evaluate

- problem statement and understanding
- learning objectives
- methodology used
- problem solution under the theoretical and practical headings
- calculations, simulation execution, and software selected
- practical results, presentations, and the printouts

An original toolbox *eDrive* opens multiple possibilities for learners and instructors [20]. It was developed to support the course in accordance with the project-based requirements as well as to assess the goals. The main features of an educational soft tool that discern it from the models meant for the professional designers are as follows:

- descriptiveness and compatibility of results
- clearness of physical essence
- suitability of report generation and format conversion
- independence of particular company interests
- matching the standards and design rules
- availability of learning-oriented manuals, textbooks, and guides

The described software offers solutions to the next typical educational and project management problems:

- informational support in electrical, mechanical, and electronic equipment selection
- mathematical and computer simulation and full computation with the use of databases
- testing and result verifying in accordance with different criteria
- drive tuning and load optimization

The toolbox includes the next components:

- powerful database
- set of adjustable controller schemes
- models of motors, converters, and gears

- graphic package for representation of the steady-state and dynamic simulated processes with an automatic and manual scaling, report generator, system analyzer, and preview facilities
- signal generator to produce the test reference and load signals as well as the nonlinear curves, noses, and filters

Thanks to the strong mathematical core, it supports all the laboratory works of the departmental curriculum. Moreover, the environment provides a possibility to simulate the same assignments using equipment of a number of companies that cannot be acquired in the institution. Comparison and discussion of the results obtained serve as a very beneficial instrument in the development of student skills and experience by using both simulations and the real equipment.

The following principles underlie project-based learning:

- students are encouraged to work regularly throughout the course and to take an active role in their learning process
- active and reciprocal interaction appears between students and lecturers as well as among the students themselves
- the course content focuses on essentials and emphasizes comprehension of overarching principles
- students are stimulated to obtain relevant concepts and knowledge from preceding courses
- students have to use the new concepts, and conceptual understanding is valued
- teaching of the new content is connected to the students' prior knowledge

Thanks to project-based learning, the staff, students as well as the community have benefited. Industry relevant projects provide students with knowledge of how theory can be related to current industrial practice. Students show a lot of interest and enthusiasm while working on projects. The work gives a holistic approach to student learning as it integrates the commercial projects with the core courses and learning objectives. Students' technical skills are tested when working on designing, building and testing the project. While designing the project, the students integrate and connect knowledge from various courses to work on an optimized solution for the mentioned problems in the project. They have to know the background theory and consider all practical issues while designing. Project design also tests the mathematical skills of the students. After designing a module, the students use software simulations to test the design before they actually build it, thus checking the ability to use computer software appropriately.

Once the module is simulated, the students build some of its components using a laboratory platform, thus obtaining their manual skills. The laboratory equipped by the leading companies in the field accompanies the study. It includes a number of test benches the most part of those supports the e-learning on-site and off-site activities [23], [24], [25].

IV. COLLABORATIVE LEARNING

As with any engineering discipline, Electrical Drives and Power Electronics are based on the integration of multiple fields of knowledge. Insofar as a certain number of systems with the components of different nature are merged, a conflict between technological complexity, cost, and simplicity of maintenance naturally occurs. The corresponding educational aim is to teach specialists working at the intersection of electronics, mechanics, and control. Course assignments and master's thesis are suitable tools for this kind of training.

Collaborative learning has become a necessary part of the project-based approach. To stimulate teamwork, a specific team-based methodology has been developed [15]. The goal of the collaborative design is to build effective real-world electromechanical equipment.

One of the typical course projects is devoted to the design of the robot drive system. Schematic plan of the transportation robot is given in Fig. 3. The work includes two stages: the stage of individual creativity and that of collective work, particularly via the Internet. These phases are detailed in Table 2.

TABLE 2. STAGES AND DISCIPLINARY BASES OF DESIGN

| Stages and items | Disciplinary base |
|---|---|
| <i>Individual design stage</i> | |
| 1. Force, torque, and power computation | Mathematics, physics and computer science |
| 2. Equipment selection | Database theory |
| 3. Optimization of the electrical drive content | Function analysis and optimal control theory |
| 4. Synthesis of regulators | Discrete mathematics and control theory |
| <i>Collaborative design stage</i> | |
| 1. Composition and interrelation of axes | Linear algebra and programming |
| 2. Trajectory description | Mathematics and numerical control |
| 3. Motion programming | Programming, CAD |
| 4. Estimation of the project | Function analysis, reliability, and economics |

In the first part, each student designs a drive of one of the mechanisms: the carriage, the arm, the lever, or the capture. For the forces, torques and power calculations, the data of the inner mechanisms are required, thus co-operation is needed to obtain a successful result. In the second part, the intercommunications of the robot sub-systems are organized.

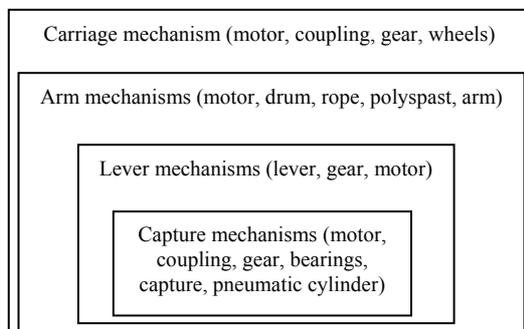


Figure 3. Schematic plan of the transportation robot

Programming of motion, efficiency, and economic evaluation depend on the joint efforts and personal solutions. The same concerns the overall estimation and project assessment.

The final and the most important part of the project is integrating the various modules and testing the overall functioning of the project. This part needs programming and debugging skills. Students learn about project management when they work on resources, timelines and procurement of components. The generic skills are tested based on students' attitude when working in teams and submitting the technical report on the project. Hence, working on a project covers all the aspects of learning.

A student group comprises usually 15 to 20 participants, randomly shared into 4-5 interaction-oriented teams with a proper mix of both academically weaker as well as stronger students. This grouping is done at the beginning of the course when the learners are informed about the practical set of the discipline that would require the study of real world systems and that the teams are a key component of the project. For each problem, the team is encouraged to elect a leader who would organize work distribution. Team leaders are appointed by the course lecturers to coordinate group activities and ensure close interaction among all team members. All teams are charged to meet regularly and to achieve the set objectives on the event driven basis. The students are assigned 12 weeks to work on the research problem. They distribute the work amongst themselves, with team members performing tasks such as searching for information from various resources, compiling the data, doing calculations, performing experiments and finally recording the work done and preparing a presentation. Ideally, these various tasks are rotated among the team members. The teams discuss issues, decide their own theoretical, practical and software goals and explore these learning and mistakes. This encouragement is given by continuous monitoring and by instructing them to record each relevant finding, any mistakes committed and the corrective action taken. Once the team members reach the solution, they are also asked to frame similar kinds of problems and identify application areas. Throughout, they are guided by an instructor who would correct students as they encounter difficulties and help them to draw conclusions to reach the desired goal.

The project is worth 30 to 50% of the final grade and the remaining 50-70% is covered in the course examination. The criteria used to score the students are listed in Table 3.

TABLE 3. SCORING CRITERIA

| Item | Score |
|------------------------|---------|
| Problem formulation | 3 – 6 |
| Team participation | 5 – 10 |
| Minutes of meetings | 5 – 6 |
| Report | 5 – 10 |
| Proposed system design | 5 – 10 |
| Presentation | 7 – 8 |
| Total | 30 – 50 |

As a result of the project-based collaborative learning, the average student final grade increased 1,4 times as compared to the traditional approach and reached 4,3 on the 5-based assessment scale. The students interested in active approach

obtained the highest scores whereas the weak students also improved their results to some extent.

Thanks to the team-based approach, the students not only maximize their practical learning experience to achieve the project goals, but also develop other important abilities in the following:

- *self-directed learning* – as a project may involve multidisciplinary knowledge which is not covered by the standard lecture material, students are driven to study and seek solutions which serve to enhance their understanding of the theoretical material
- *project management* – students organize a task based on the talents of each group member, and each defines their own task and manages their progress against a specified timeline
- *product design* – students have more scope to develop the project so as to display their inventiveness

V. CONCLUSION

The proposed project-based collaborative learning approach encourages the reinforcement techniques that focus on a conceptual understanding and new opportunities for students to choose the content and study methods. It shows students that teaching is stimulating and caring and gives them time to process the concepts in contrast to overworking within the course or curriculum. Students who take an active approach to learning reach a higher, more integrative level of understanding and demonstrate longer retention of the material. Engineering graduates of this type have a strong inclination to apply the type of learning that forces passing the courses. Since a student's orientation to learning can be modified by the course environment, instructors have the possibility to influence which approach a learner will adopt.

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REFERENCES

- [1] T. A. Hudson, M. Goldman and S. M. Sexton, "Using behavioural analysis to improve student confidence with analog circuits", IEEE Transactions on Education, 2008, vol. 51, no. 3, pp. 370-377.
- [2] C. Savander-Ranne, O.-P. Lunden and S. Kolari "An alternative teaching method for electrical engineering courses", IEEE Transactions on Education, 2008, vol. 51, no. 4, pp. 423-431.
- [3] R. Magdalena, A. J. Serrano, J. D. Martin-Guerrero, A. Rosado and M. Martinez, "A teaching laboratory in analog electronics: Changes to address the Bologna Requirements", IEEE Transactions on Education, 2008, vol. 51, no. 4, pp. 456-460
- [4] J. Mills and D. Treagust, "Engineering education – is problem-based or project-based learning the answer?", Australasian Journal of Engineering Education, 2003, pp. 18-30.
- [5] C. Aldrich, Learning by Doing: A Comprehensive Guide to Simulations, Computer Games, and Pedagogy in E-Learning and Other Educational Experiences, NY: J. Wiley & Sons, 2005, 356 p.

- [6] G. Wang, "Active learning in digital electronics: Preview, exercise, teaching and learning", The 2nd International Multi-Conference on Engineering and Technological Innovation (IMETI'2009), Orlando, Florida, 2009, pp. 219-223.
- [7] J. Macias-Guarasa, J. M. Montero, R. San-Segundo, A. Araujo and O. Nieto-Taladriz, "A project-based learning approach to design electronic systems curricula", IEEE Transactions on Education, 2006, vol. 49, no. 3, pp. 389-397.
- [8] R. H. Chu, D. D. Lu and S. Sathiakumar, "Project-based lab teaching for power electronics and drives", IEEE Transactions on Education, 2008, vol. 51, no. 1, pp. 108-113.
- [9] A. Mantri, S. Dutt, J. P. Gupta and M. Chitkara, "Design and evaluation of a PBL-based course in analog electronics", IEEE Transactions on Education, 2008, vol. 51, no. 4, pp. 432-438.
- [10] R. Garcia-Robles, F. Diaz-del-Rio, S. Vicente-Diaz and A. Linares-Barranco, "An eLearning standard approach for supporting PBL in computer engineering", IEEE Transactions on Education, 2009, vol. 52, no. 3, pp. 328-339.
- [11] L. Roberto de Camargo Ribeiro, "Electrical engineering students evaluate problem-based learning (PBL)", International Journal of Electrical Engineering Education, 2008, vol. 45, no. 2, pp. 152-161.
- [12] V. Vodovozov and Z. Raud, "Model-based learning in electric drive design", The 2008 European Simulation and Modelling Conference (ESM'2008), Le Havre, France, 2008, pp. 355-359.
- [13] M. Savin-Baden, "Problem-based learning in electronic engineering: locating legends or promising problems?", International Journal of Electrical Engineering Education, 2008, vol. 45, no. 2, pp. 96-109.
- [14] J. E. Mitchell and J. Smith, "Case study of the introduction of problem-based learning in electronic engineering", International Journal of Electrical Engineering Education, 2008, vol. 45, no. 2, pp. 131-143.
- [15] V. Vodovozov, "The educational resources of mechatronics", Mechatronics, 1995, vol. 5, no. 1, pp. 15-24.
- [16] R. Corden, "Group discussion and the importance of a shared perspective: learning from collaborative research", Qualitative Research, 2001, vol. 1, no. 3, pp. 347-367.
- [17] T. A. Wasonga, "Using technology to enhance collaborative learning", The International Journal of Educational Management, 2007, vol. 21, no. 7, pp. 585-592.
- [18] E. Butun, C. H. Erkin and L. Altintas, "A new teamwork-based PBL problem design for electrical and electronic engineering education: a systems approach", International Journal of Electrical Engineering Education, 2008, vol. 45, no. 2, pp. 110-120.
- [19] F. Roos, H. Johansson and J. Wikander, "Optimum selection of motor and gearhead in mechatronic applications", Mechatronics, 2006, vol. 16, no. 1, pp. 63-72.
- [20] V. Vodovozov and A. Loparev, "Simulation tools for design and testing of electric drives", 10th International Power Electronics and Motion Control Conference (EPE-PEMC'2004), Riga, Latvia, 2004, DS 7.16.
- [21] V. Vodovozov and J. Laugis, "Object-oriented electric drive development technology", IEEE International Electric Machines and Drives Conference (IEMDC'07), Antalya, Turkey, 2007, Paper AF000434.
- [22] V. Vodovozov and D. Vinnikov, Electronic Systems of Motor Drive, Tallinn: TUT Publishing, 2008, 248 p.
- [23] T. Jalakas, V. Vodovozov and D. Vinnikov, Power Electronics: Laboratory works, Tallinn: TUT Press, 2008, 30 p.
- [24] T. Jalakas, V. Vodovozov and D. Vinnikov, Advanced Course of Power Electronics: Laboratory works, Tallinn: TUT Press, 2008, 28 p.
- [25] N. J. Powell, P. J. Hicks, W. S. Truscott, P. R. Green, A. R. Peaker, A. Renfrew and B. Canavan, "Four case studies of adapting enquiry-based learning (EBL) in electrical and electronic engineering", International Journal of Electrical Engineering Education, 2008, vol. 45, no. 2, pp. 121-130.