Project-based Learning Approach in Teaching Power and Energy Engineering Courses

Dr. Radian G. Belu, Southern University

Dr. Radian Belu is Associate Professor within Electrical Engineering Department, Southern University, Baton, Rouge, USA. He is holding one PHD in power engineering and other one in physics. Before joining to Southern University Dr. Belu hold faculty, research and industry positions at universities and research institutes in Romania, Canada and United States. He also worked for several years in industry as project manager, senior engineer and consultant. He has taught and developed undergraduate and graduate courses in power electronics, power systems, renewable energy, smart grids, control, electric machines, instrumentation, radar and remote sensing, numerical methods, space and atmosphere physics, and applied physics. His research interests included power system stability, control and protection, renewable energy system analysis, assessment and design, smart microgrids, power electronics and electric machines for non-conventional energy conversion, remote sensing, wave and turbulence, numerical modeling, electromagnetic compatibility and engineering education. During his career Dr. Belu published ten book chapters, several papers in referred journals and in conference proceedings in his areas of the research interests. He has also been PI or Co-PI for various research projects United States and abroad in power systems analysis and protection, load and energy demand forecasting, renewable energy, microgrids, wave and turbulence, radar and remote sensing, instrumentation, atmosphere physics, electromagnetic compatibility, and engineering education.

Dr. Alexandru Belu
Dr. Zhengmao Ye, Southern University

Dr. Ye's research interests include "Control and Optimization with Diverse Applications on Electrical, Mechanical, Automotive and Biomedical Systems, as well as Signal Processing and Image Processing".

1. Power Engineering Education Status

Emerging trends in STEM education have continued to call for quality education that is fostering the ability of graduates to meet the challenges of the 21st century industry, while encouraging their participation in sustainable development. Energy and power industries are the cornerstone of prosperous society, while all the critical and crucial socio-economic functions depend on the secure, sustainable and reliable power and energy infrastructures. There are recent recognitions and acknowledgements of the needs to improve, restructure or rebuild curriculum and revitalized and reform energy and power engineering education. Equipping students with the skills and knowledge required to be successful engineers in the 21st century is one of the primary goals of university educators [1-5]. Enabling students to practice self-learning, to find solutions to design problems that are sustainable, helping them recognizing that they are part of community are just a few of our educational goals. Energy and power engineering education has undergone significant changes over the last decades, together with an increased student interests into such engineering programs. The issues surrounding this theme are also receiving significant interests form faculty and quite often administration. Today electrical energy industry professionals are required to have significant techno-scientific capabilities, deep interdisciplinary understandings, and soft engineering skills, such as self-learning abilities, leadership, team work, communication, project management, and interpersonal competence. However, how and which are the best approaches to better educate the next generation of power and energy engineers, remain open questions. In addition of teaching courses in electrical machines and power systems, higher education institutes must include new courses and topics into curriculum, such as renewable energy systems, power electronics, smart grids, energy economics and management, to mention a few of them while still ensuring a four-year graduation timeframe [2-9].

The modern power systems have been significantly changed from the very modest beginnings to one of the most complex and large system, perhaps the largest machine or enterprise ever built by human beings. The world power and energy infrastructures are facing structural changes including liberalization of markets, extended uses of smart sensing and monitoring, two-way communication or integration of renewable energy sources. The power and energy industry in the 21st century is going through an evolutionary period, while new technologies are changing the way we generate, transmit and deliver electric power. The electric power industry has many new power grid applications in the forefront and implementation phases. The power system and its wiring connect nowadays every single house to each other and to the power stations together within a country or region. Furthermore, countries are inter-connected together so that whole continents are joined together to enable smooth, reliable, secure and economical production and transportation of electric energy. This huge system needs efficient automation, smart sensing and monitoring, intelligent management and control with real-time and two-way communication. In the same time, the unprecedented economy globalization has amplified the technology and sciences impacts on our society in ways that have not been predicted. The connectivity provided by the internet and communication technologies (ICT) has generated new products, services, capabilities, new market opportunities, making in the same time available workforce that is often well-educated and cheap. This is likely to have profound impacts on the wealth distribution in developed and developing countries and may change the socio-economic structure of countries where the population general wellbeing has been taken for granted. Power and energy industries are going through evolutionary periods, while technologies are changing the way the electricity is generated, transmitted, delivered and used, with new applications in the forefront. Workforce demands in power industries are evolving with new and extended expectations and requirements. In order to be a successful proficient power engineer in the 21st century, one must have multiple skills in cross disciplinary areas. The industry is demanding engineering education to broaden in areas such as computing, networking, control, power electronics, data analytics, along with information security and business that contribute to match the engineering ingenuity with smart grid dynamics [1-14]. The academia is witnessing power industry evolutions, while looking and searching into ways to evolve, adapt, and restructure curricula to train productive and qualified power and energy engineers. Universities and colleges need to do further research to understand the industry trends, needs and expectations, by collecting information as to what has changed and what are currently the industry best practices. The challenge faced by academia is to come up with an updated curriculum at both the undergraduate and graduate level. While the power and energy technologies keep evolving at fast pace, it is the right time to adapt the power and energy engineering curricula to meet the industry expectations and needs. By making power engineering education more relevant to present and future industry needs, a new graduate is more skilled and able to adapt to the future work environment, contribute towards the potential employer goals.

Traditionally, in development of power and energy engineering education the key objective was to enable the teacher to convey knowledge and insight to the students. The main element was (and still often is) the lecture, in which the teacher explains, gives examples, shows calculations, discusses mathematical derivations, concepts, operation principles, etc. The accent was on the oral communication, which was supported by hand written messages using the blackboard and chalk, power point slides, etc. However, several studies have found that students' mastery of content knowledge increases when they are engaged in problem-based learning (PBL) and project based learning (PjBL) [10-24].Curricula must focus not only on the theoretical basis of energy systems, but also on the experimental works of power technologies. This point of view is important in power and energy engineering studies, consisting of mixtures of power electronics, energy conversion, electric machines, electric circuits, computing, signals and systems, communications, and electromagnetics. Promoting, adapting, and restructuring power engineering disciplines can be done by defining a new curriculum that includes news courses, new laboratories or new topics in which the students develop whole systems involving multidisciplinary knowledge. In such a multidisciplinary education context, PBL and PjBL methods appear as ones of the most interesting and effective instructional strategies. Moreover, the accreditation requirements, industry and governmental organization needs and expectations are pushing the engineering programs to find creative ways to include service oriented and multi-role projects, multi-disciplinary team, soft and leadership skills into their curricula and courses.

This paper presents a project-based approach of power engineering, emphasizing on design, project management, multi-role project (MRP) paradigm that are complementing and enhancing traditional teaching and learning methods in this dynamic engineering field. Course development are discussed, and project selection and management is emphasized. This analysis was done to predict the effectiveness of project-based instruction for programs related to power and energy engineering, power electronics, and renewable energy. A curriculum for power and energy engineering minor based on project based learning (PjBL) methodology is in process development and implementation [9-11, 14-23]. Although the educational program is based on PjBL, this minor is comprised of two types of courses. Some courses are based on a combination of lectures, tutorials and problem-based learning (PBL) techniques, while others are based on

PjBL approach in an extended way. As an example of a fully PjBL study units are Introduction to power systems and power electronics courses. For delivering the course in PjBL, an integrated electric machines, energy conversion, power electronics, and power systems laboratory has been proposed, approved and in process to be established, giving the students access to professional software packages, tools and settings similar to ones found in energy and power industries. Real-world industry-relevant projects are proposed in the areas of power electronics, power system operation, planning, and power distribution. These projects are used as stimuli for student learning and retention. An extended assessment portfolio is proposed to assess students learning outcomes, and the students' feedback and inputs will be used to make changes and adjustments. Lessons learned will be made available for interested parties, instructors or researchers. While any feedback or suggestions from other instructors or professionals are highly appreciated.

2. Project-based and Problem-based Learning Approaches

Innovative curricula, such as problem-based learning or project-based learning, put the students' engagement, involvement and persistence to the test, placing a lot of weight on students' involvement during their university years. PBL, PjBL and their derivatives usually require students to participate willingly in the meaningful learning activities proposed, mostly teamwork. The design of these innovative curricula needs that students develop more autonomy, responsibility, and self-awareness about the value of these student-centered activities [9-30]. The best approach is to analyze all the issues and challenges discussed above and make suggestions and propose solutions. We begin by reviewing and analyzing the current teaching practices, strengths, limitations, challenges and issues, learning goals and objectives, examining the links between the goals and objectives, design, content and structure of each electrical engineering course, current assessment practice, and things that need to be changed. We need to explore and analyze data, such as: What a graduate know or be able to do? What are the strengths and weaknesses of the program disciplines? What we need to preserve from current curriculum and what not? Where are the curriculum's areas that need to be strengthen? This research and questions require in-depth analysis of current teaching practices, program goals and objectives, a comprehensive reexamination of the links between program goals and objectives, course design and structure, student learning outcomes, and the course assessment. Ultimately, we have to develop adapted teaching strategies and approaches, or how new technologies can support learning processes. Design projects play a vital role in providing students with a crucial attribute desired and required by the industry and governmental organizations, including armed forces: the ability to identify and define problems, develop and evaluate alternative solutions and designs, effect, implement and test one or more design alternatives to better solve the problem. It is agreed that such attribute can only be developed by exposing students to the experience of open-ended problem solving which includes linking engineering science knowledge to complex, real-life design problems. Apart from the engineering and technical issues, these problem solving activities should include extra- and trans-disciplinary and soft factors, such as economic, environmental, sustainability, manufacturability ethical, health and safety, social and political considerations. It is well-accepted that such problem-based learning type is only achieved by using quite complex project scenarios, and therefore requires careful planning and integration into the rest of the curriculum in order to prevent students from being seriously overburdened and confused. Professional life today is increasingly interdisciplinary and challenges engineers to learn to interact with others, to give and accept criticism, and also to listen to and understand alternative viewpoints. However, collaboration is a process, and students need help to practice teamwork skills like conversing and listening, leadership, conflict management, decision making, confidence building, and finding compromises. However, strong and solid engineering and basic sciences knowledge and conceptual thinking are now considered more important than before.

Project-based learning has been proven to be an attractive and effective method which can improve engineering education significantly [9-33]. Project-based learning is a dynamic approach in which students explore real-world problems and challenges. Students are motived with the PjBL scenario compared to the traditional teaching method, in addition the instructors can benefit from it in guiding students to achieve significant learning. Moreover, the PjBL and PBL methods have been widely used in electrical engineering relevant courses, such as electronics, communication, power electronics, control, instrumentation and power systems, and obtain a promising teaching and learning performance [9, 12-33]. With this type of active and engaged learning, students are inspired to acquire deeper subject knowledge. Particularly, using PjBL approaches to the electrical engineering courses can increase the challenges for students and thereby their motivation and interests. Bearing this in mind, instructors can give specific objectives, contextualized within the subject requirements, formulated as competencies which the student must have acquired by the end of a power engineering course, such as:
1. Providing the students with the fundamental power and energy engineering concepts and to prepare them for advanced study in electrical engineering areas.
2. To learn how to search for, classify and analyze technical information about equipment, device or component datasheets and to be able to identify suitable information sources.
3. To provide hands-on and experimental experience to supplement theory in power and energy engineering and to promote the application of theoretical concepts.
4. To provide students with the ability to find solutions to the problems and to enhance their critical reasoning needed to choose the appropriate solution in accordance with specific criteria.
5. To enhance other competencies within the engineering, such as: the ability to write good technical reports and to make presentations, project management and economics, and team-work.

Having defined the course objectives, goals and outcomes, based on the available educational resources and support, the instructor have to select the most suitable methods to obtain these goals and outcomes. PjBL and PBL methods were chosen because it prompts the students to encounter the core concepts and principles, while managing a specific project, thereby enabling the acquired knowledge application [15-30]. PjBL goes beyond the relationships between knowledge and thinking, helping students to *know and to do*. In fact, it is focuses on *doing something* and *learning on the way*. PjBL main features from the student learning viewpoint are:
1. In PjBL or PBL the focus is on the student competencies to design and to reach the solution, around students' concerns and skills, the end product being a reflection of them.
2. In PjBL the students solve problems, through self-management, project management, and critical knowledge are enhanced, as they manage the work, offering frequent feedback, self-assessment and consistent opportunities for students to learn from experience.
3. PjBL and PBL recognize the student capacity to perform important works, placing them at the core of the learning process, engaging and motivating almost all students.
4. PjBL create positive collaborative relations, instructor and students, creating performing classrooms, forming powerful learning communities focused on achievements and surpassing.
5. PjBL and PBL are stimulating acquiring knowledge, competencies, and significant learning.

Within the multidisciplinary educational context of the power electronics, PjBL and PBL approaches appear effective, efficient and interesting instructional strategies. In summary, the PjBL or PBL strategies aim to engage students in authentic real-world tasks and open-ended projects that can increase the motivation and interests for most of the students. However, there are other additional reasons and rationale for our decision to use the PjBL in teaching the power engineering courses. It is our strong believes *that good teaching, a constant reassessment, updating, and content adjustment, structure and presentation is enhanced by an atmosphere where the research transpires; where the research enhances and energizes the curriculum, course content, and the students which in turn can only have positive impacts on the research that drives them*. In our views, the project must be included, not only in all core upper division courses, but also at sophomore and even freshmen levels, with the project topics selected form the emerging engineering areas (e.g. renewable energy, distributed generation, smart grids, robotics, wireless sensor networks, or mechatronics) have a positive effects on the student motivation, interests and ultimate retention and success. Second reason was the initial lack of adequate laboratory infrastructure, insufficient fully operation laboratory workstations, obsolete, incomplete and old equipment making all power engineering, electric machines or power electronics settings, being no exception hard to set, run and perform [9-39].

2.1 Multi-role Project Paradigm

Understanding the central ideas of the power and energy engineering domains, comprehending the relationships between basic concepts, and applying main relationships in problem solving should be encouraged. As in any complex and challenging subject areas, it is important to structure the contents of the design curriculum carefully and introduce new topics and aspects in a logical and consistent way. We are proposing to study the effectiveness of an updated approach of the PBL and PjBL paradigms, through the multi-role project (MPR). The MRP has pedagogical goals liked to both subject-matter content and the development of high-level skills. MPR is based on meth-principle that carrying-out a student project is a role-paying game consisting of two sections performed by the team: a learning project and an engineering project. MRP provides a conceptual framework, consisting of distribution of responsibilities, team interactions and solicitations, continuous improvements and anticipation, alternating individual and/or teamwork, positive interdependence, open communication, entrepreneurship, leadership and management. Role-pay is an important education concept, defined into the PJBL and GBL paradigms. The MPR methods in the general PjBL and PBL approaches was proposed and used by Professor Bruno Warin and his group at Université du Littoral Côte D'Opale, France [31-33]. A few of the ECE courses will be restructured into the frame-work of the Problem and Project Based Learning, Gaming Based Learning (GBL) and Multi-Role Project Paradigm. A serious game, as applied in engineering education is asset of rules allowing interaction to acquire a goal, through a set of objectives, behaviors, rights and duties, the role, assigned to a student or to a team. The MRP roles include the team and students, engineering expert(s), the client(s) and business expert(s). There are strong evidences form the literature that including the soft skills such as management, entrepreneurship and leadership can boost the retention and enrollment in engineering programs. Entrepreneurship education has been found to boost GPA and retention rates of the engineering students, provides the students with the skills and attitudes needed to innovatively contribute to the existing organizations and pursue their own ventures, and has the potential to address current and anticipated workforce demands. We strongly believe that by integrating entrepreneurship into engineering courses, specifically in the ones that are suitable for PjBL and/or PBL approaches, the students are likely to be more connected to their learning and thus are more likely to continue with their engineering studies. The perspectives of these graduates align with employers, who indicate that communication, problem solving, and the ability to apply knowledge is essential for graduates. Also important, but generally lacking, are effective communication and team work, the ability to understand contexts and constraints, and the ability to innovate. All of such skills are generally well addressed by the entrepreneurship and leadership education and including such concepts into our engineering curriculum. The biggest challenges in adopting interactive teaching methods, PBL and PjBL may be the lack of complete teaching materials, or suitable and appropriate projects. Most papers on education research concentrate on the theory behind methods or they report the research of learning outcomes without giving any concrete examples of the exercises, questions, or task formulations. However, designing and implementing exercises which support and encourage interaction is probably the most challenging task [31-42]. We are proposing to address these issues and challenges to an overall literature search, carefully analyzing and revising course content and materials and developing suitable project topics. For example, power electronics and power systems design examples, proposed to be developed during our project are useful for students to understand applications of designed devices and systems in real practical applications. As part of our project a set of new type computer-aided programs for classroom and distance learning are proposed to be developed. It believed that they will improve students' learning and interests, while coping with some of the challenges faced by instructors during spring and fall 2020.

According to Professor Warin and his team at the Université du Littoral Côte D'Opale [35, 40, 41], MRP approach has the educational objectives linked to subject-matter content acquisition and the development of high-level engineering skills. MPR expected outcomes attempt to integrate various high-level skills, accustoming students to reflect on their activity, while facilitating the instructor or advisor work in supervising students and project teams. In MRP approach, the learning goals are collected in a *pedagogical project* or an *educational progress report*. MRP paradigm provides a conceptual framework, consisting of five principles, the distribution and sharing of responsibilities, the interactions and solicitations, project quality, individual vs. team work, and the content and communication to implement, manage and organize project team operation. The engineering project involves creating a product or service for the customer (client). This varies in nature and scope, e.g. a feasibility study for an innovative consumer item, a website programming, or a power source design. From a practical viewpoint, it is often better to give the student a *realistic* rather than a *real project*, because with the former the instructor can better define the pedagogical goals. In the case of an actual project for a real client, there is always the risk of failure, for example such client may not be available, may decide to abandon the project, etc. The *learning project* involves the student acquiring a pre-defined body of knowledge, falling into two groups. The first one concerns skills for the 21st century, notably those related to project management. The second group concerns professional skills related to the project deliverables. For both groups, the learning project should specify what know-how, skills or competences will be acquired, and to what level. Each of these two knowledge groups is first ranked according to one of five acquisition levels: know, apply and/or understand, master (understand and apply), adapt, and innovate. The selected levels [35, 40-42] are classified by the five achievement levels: 1) initiated, 2) partial, 3) quite good, 4) good, and

5) excellent. This classification is partly empirical and depends on the expertise of the instructors.

In the Warin group's views, the role-play is an important and educational research concept, in the case of poorly-defined roles, can have significant negative effects on teamwork [33-35, 40-42]. This concept is corresponding in the MPR paradigm to the work responsibility concept. The game concepts are defined as a set of rules, allowing people to interact with each other to accomplish a goal. In a game, the set of objectives, behaviors, rights and duties assigned to a person or a group of persons is called a role. Notice a participant may have several roles, or inversely, a role may involve several students and/or instructors. MRP approach involves four major roles: 1) *a student and a team* apply the method, carry out the work for the client, while improving their project and professional skills; 2) *MRP expert* helps the teams understand and apply MPR technology, ensuring that the methods are properly used (MRP expert role integrates the tutor role, assisting the students in learning and in performing their two projects; 3) the *client* defines the engineering project goals, validates them, finally receiving or using the project deliverable(s); and 4) *the business expert* has skills and knowledge in a specific learning domain required in the engineering project, answering to team questions, advising and providing, if needed, with tutorial(s) or lecture(s), thus replacing in many ways traditional instructor role. The last three role-players are also project and team evaluators, participating in the teams and students assessments and evaluations. For the students, the priority is to learn their role while performing the project. For the other MPR actors (the supervisors) the main priority is to interpret the roles entrusted to them for the benefits of the students [33-35, 40-42].

In the French group approach [33, 40, 41], the students are applying further principles to provide a conceptual framework for the development and implementation of their projects (both learning and engineering). The first principle refers to the *distribution of responsibilities*, based on the premise that there is no an effective and productive teamwork without a distribution of responsibilities, MRP method requires teams systematically and periodically to define, re-assesse, redistribute and share responsibilities. The second principle refers to the *regular interactions and solicitations* within the team, based on the premise that any project advances better and faster if there are regular interactions, as well as the solicitation form the advisor(s)/supervisor(s) within the team, e.g. regular communication, project progress reports presenting current and future tasks of each team member, and the completion of the project sub-tasks and phases necessary to the final deliverables or prototype. Notice that regular team only and team-instructor-advisor meetings provides the project progress and monitoring framework. The usually meeting formats include team or part team and the advisor/supervisor and may include the project client if any. Third principle, the *anticipation and continuous improvement*, specifies that smooth project teamwork depends on the anticipation, while project quality depends on continuous improvement. Anticipation and continuous improvement are applying to both the learning project and the engineering project. For each of them, the students need to make schedules, to regularly monitoring their progress, summit to the advisor(s) a biweekly project progress reports and, if needed, modify the project subtasks for the team members or require advisor and expert assistance. *Positive interdependence, alternating individual work with team or collective work* principle states that effective and efficient teamwork is organized with an interdependence between team members (each team member needs one or more team members to make progress), while alternating individual work with collective work, to compensate for the relative slowness of collective work [40-42]. *Open communication and content management* principle states that teamwork must be based on communications and project management. In addition to meetings, the team should maintain a project progress tracking (e.g. a website or a project notebook) as the main vector of communication and project management, used to monitor both the learning and engineering projects. In this website or project notebook, teams are summarizing their project progress, issues, problems, etc. However, the oral presentations at the end of the semester give a more detailed description of both engineering and learning projects. It is recommended that in project notebook and website to include pages, such as: *project home, team members, meetings, deliverables, presentation or links*. In our MPR implementation the Moodle learning management system was used to implement and manage the senior project design teams' websites (the project homes). Short profile of the team members is included in each project home, while the meetings page links all project progress reports. On the deliverables and links pages are including project deliverables and the status, as well as useful information and references related to the project.

2.2 MRP Implementation in Power Electronics and Capstone Design Courses

Power electronics represents the application of electronic circuits to energy conversion, transfer and processing. Study of the characteristics, capabilities and limitations of power semiconductor switching devices is fully discussed, during the course, as well as the analysis, design and simulation of common circuit topologies for power conditioning and processing, power electronic converters, or switch-mode power supplies. Power electronics applications are also discussed in details, focusing on the renewable energy and power systems. Power electronics course goals include the understanding of the characteristics and operating principles power electronic devices and their application in power conversion and conditioning technologies. A major goal is the students are gaining an understanding of the methods of analysis and design appropriate to power electronic converters, e.g. rectifiers, inverters, DC choppers, cyclo-converters and drives, as well as their performances, factors affecting their operation, etc. After completing the course the students will know how to use simulation software such as MATLAB, LabVIEW and PSpice for power converter design and simulation. One of the main objectives of the power electronics course is to present, cover and discuss the fundamental concepts, basics of industrial and power electronic converters over a spectrum of applications and to provide an introduction to the emerging technologies in these fields. Upon completion of this course the students are expected to be familiar with: power computation, concepts, power switching devices, DC-DC, DC-AC, AC-DC and AC-AC power converters, switch-mode power supplies, and drives, as well as with extended utility, renewable energy and power processing applications of power electronics circuits [36-39]. The course format makes the students gradually more responsible for the analysis and design of the circuitry, control and components which permits nominal operation of the power converters. The course experience culminates with a mini project where students analyze, design, simulate and demonstrate power electronics concepts. The project is replacing one of the in-semester tests. Each project is carried out by a team of three or four students, often one project is focused on the renewable energy.

Our two-semester senior design course focuses on planning, development, and implementation of an engineering project, which includes two formal reports, project documentation, two oral presentations, and prototype demonstrations. The course goals are to develop the students' ability to manage projects involving system design, test and implementation. In these two courses, the students are expected to effectively manage their time and team efforts to produce a finished and workable prototype at engineering standards and expectations. Progress formal reports, written reports and oral presentations constitute integral components of this course sequence [35, 40-42]. Before beginning the projects, student teams are provided with adequate training in project formulation, engineering ethics, management and resource analysis, performance goals, objectives and team expectations, public presentations of project work, and individual project supervision. The design fundamental elements are: the establishment of the system objectives, synthesis, analysis, construction, testing and evaluation. In our senior design we have placed this definition at the core of our courses. First we focus on system (project) objectives and ask the teams to write a short project proposal stating these objectives, the decisive and critical factors, constrains, and requirements to reach the stated system goals. Our projects may involve elements of structural design, energy resource assessment, power and energy storage management, electromagnetic compatibility considerations, signal processing and conditioning, optimization, electrical, electronics, thermal, and computer engineering system design. The second phase is conceptualization and laying down how to achieve the stated objectives. At this point the students are encouraged to draw a block diagram of the design. A set of questions are posed to students to further understand this task. These are some of the typical questions:

- What are the inputs to the system and, what are their characteristics and magnitudes?
- Do the inputs require conditioning?
- What is the medium through which inputs are interfaced to the system under consideration?
- Do the inputs dictate to the system design, and how to behave, or just activates the system?
- What are the load requirements?
- Is it a single output or multi-output system?
- Are there feedback loops in the system?
- Do the loads require separate power supplies?

Once the students compile the answers to these questions, they are directed to perform system analysis, start the design, component selection, purchase and/or fabrication, and finally the prototype building and testing, as well as the overall design improvements or optimization. For example for a project of and energy harvester, the system objectives and requirements include: the system must be reliably and operate autonomously for a minimum five-year period, with no maintenance while capturing enough energy to fully power the wireless sensor node components (sensors, microcontroller, data storage, power management unit, receiver and transmitter). The node power consumption is in the node main components: sensors, microcontrollers, power convertors and all other electronic devices and circuits used for the node power management and for radio communication, and must be properly sized and optimized. The energy harvester system also needs an energy storage unit to store excess energy, and to power the node in the event that energy sources are not producing any or enough energy due to the weather conditions or other unexpected reasons. The system must be mechanical resistant to the outdoor elements, wildlife, weather impacts and other affecting or damaging treats [21-30]. As an ultra-low-power circuit, conventional limited operation life batteries used to power such systems are desirable to be replaced with smaller-size and longer life candidates. In this sense, energy harvesters hold great advantages such as almost unlimited lifetime, and no need for recharging or maintenance.

Another example of project is a standalone hybrid power system for remote locations and applications. The use of distributed and renewable energy systems, including energy storage units in remote standalone systems could help reduce the operating cost through the reduction in fuel consumption, increase system efficiency and reduced noise and emissions. In many remote villages, communication towers, monitoring stations, etc. the stand-alone power systems are often more cost-effective than utility grid extensions mainly due to the high cost of transmission lines. However, the average cost of producing electricity in such cases is still extremely high due to high cost of the transportation of fuel for diesel electric generators (DEGs). Further compounding the problem there may be environmental impact of leaking fuel tanks which are contaminating soils, air emissions from DEGs, and noise pollution. Solar PV, wind and other renewable sources of energy are being integrated with DEGs to help reduce the fuel consumed by the DEGs, significantly reducing the electricity cost. The best such projects are the ones, involving renewable energy and energy storage technologies, combining student design and faculty research efforts with private industry collaboration. The goal of such student design project is to develop a hybrid power system for a remote off-grid application, integrating renewable energy sources, energy storage units and smart control and power management with existing fossil fuel based energy sources. The criteria for the design include: finding the most economical solution in terms of lifecycle costs, making the best use of available equipment, optimizing the system performance and energy management for specific load profiles, lowering the operating and maintenance costs, and assessing the impacts of the design on the environment.

Our instruction approach and the use of PBL methods are designed to reinforce *courses, such as introduction to energy engineering, power electronics, introduction to power systems and power distribution.* During lectures, besides covering fundamental theory and concepts of a specific course, *extensive* discussions of *design and analysis methods and tools* used in modern power industry, utility grids, electronics or renewable energy conversion systems are included [33-42]. For example in power electronics course the students are provide with basic and advanced knowledge about power converter system design, convertor analysis methods, industry codes, standards and the potential specialization in this power engineering field. Students learn, verify, and reinforce lecture concepts by performing power converter experiments in the laboratory sessions and by designing a specific system, e.g. 12-V power supply for a wireless sensor node, two-axis sun tracking, voltage regulators, outdoor PV battery charger, etc. In our approach we adopted the approach, principles and methods of multi-role project (MRP) paradigm. With this approach, students can develop confidence and the abilities needed in project design, as well as in their senior capstone design courses. The design experience develops *the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification*. Through the projects, the students learn to use and understand the manufacturer data sheets, application notes, and technical manuals, which would be difficult to complete individually in regular course work, gives the students a sense of satisfaction and accomplishment that is often lacking in many engineering courses, using traditional teaching approaches. Furthermore, the design experience motivates student learning and develops skills required by the modern industries. We are emphasizing on the depth instead of breadth in each of the power and energy engineering courses, while expanding the scope and range of various topics through sequel courses. Modern simulation, analysis and design tools and software packages, similar to one used in industry are often used during project work.

In terms of the MRP approach application, each of the courses begin with introductory sessions, in which the MRP method is presented and discussed. In addition, in senior design project course sequence a set of 2-3 tutorials relevant to the project topics and course are delivered by the instructor. At the end of semester the teams gave project defense presentations, justifying project choices, decisions and design in their engineering project. Teams also the engineering and learning project reports, describing the team organization, work and individual contributions. The main goal [35-42] of the learning project is to understand the MRP method and the application in each of the selected courses. The first part of the course project is spent on the learning project, the teams and students are presenting the project deliverables, approaches, team specific mode of operation (working), project time table, or project issues. In the engineering project, first the students are producing an overall description and schedule for the chosen system (design) specifications, requirements, constrains and characteristics. During the project meeting, the instructor and/or the project advisor(s) are available to the teams, playing roles as discussed in the MRP method presentation, e.g. engineering, management and business expert, or client. The students are in charge of requesting a meeting with experts and to provide a provisional agenda, while the agenda and progress report are validated by the expert(s). In our opinion, the regular learning and engineering project deliverables motivate the students, while allowing the course instructor, project advisor and expert(s) to check the team progress in learning and the progress of the engineering project toward final design and workable prototype.

3. Conclusions and Future Work

In recent years, there has been a stronger shift from using lecture-based teaching methods in undergraduate engineering courses to using more learner-centered teaching approaches, such as problem-based and project-based learning approaches. The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in design creation, critique, and justification. Students learn to understand the manufacturer data sheets, application notes, technical manuals, component specifications and to employ the industry tools. The experience of teamwork, prototype design and test, very difficult to complete individually, gives the students a sense of satisfaction and accomplishment that is often lacking in engineering courses that are not including projects. Furthermore, the design experience motivates student learning and develops skills required in industry. The students were able to make satisfactory estimations and calculations of these projects. Their results reflect that they have understood well all the basic ingredients of the modeling techniques and design of the renewable energy systems. The MRP method, a broadly applicable PjBL approach, developed around meta-principle of role-playing game based on a learning and engineering projects. MPR is significantly heling the students to acquire knowledge, professional skills and experiences as required by the modern industries and to develop their abilities to work both in teams and individually in an organized and systemic way. In our approach, the PjBL and PBL methods used are designed to reinforce power electronics theory and concepts covered and to discuss design and analysis methods and tools used in modern power and energy industry, utility grids, power electronics or renewable energy conversion systems. It provides the students with knowledge about system or equipment design, industry codes, standards and potential specialization in this engineering field. Students learn, verify, and reinforce lecture concepts by performing power converter experiments in the laboratory sessions. In our approach we adopted the principles of the problem-learning methodology. With this approach, students can develop confidence and the abilities needed in project design, as well as in their senior capstone design courses. The design experience develops the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification. Through the projects, the students learn to use and understand the manufacturer data sheets, application notes, and technical manuals. The experience, which would be difficult to complete individually, gives the students a sense of satisfaction and the accomplishment, often lacking in many engineering courses, using traditional teaching approaches. We emphasize on the depth instead of breadth of the power electronics and senior project design courses through suitable renewable energy, power and energy engineering projects, while expanding the scope and range of various topics.

References

1. G. Gross, G.T. Heydt, P. Sauer P. and V. Vittal, "Some reflections on the status and trends in power engineering", Montreal, Quebec, Canada, 10 Oct. 2003.
2. K. C. Judson, "Restructuring Engineering Education: Why, How And When?", Journal of Engineering Education, Vol. 101(1), 2012, pp. 1.
3. 7. J. E. Froyd, P. C. Wankat, and K.. Smith, "Five major shifts in 100 years of engineering education", Proc. IEEE, Vol. 100, 2012, pp. 1344-1360.
4. D. Grasso, D. and M. Brown Burkins, M. (Eds.), "Holistic engineering education: Beyond technology", New York, NY, Springer, 2010.
5. P.W., Sauer, G.T., Heydt, and V. Vittal, "The state of electric power engineering education", IEEE Transactions on Power Systems, Special section on Education, 2004.
6. M. Crow, "Supportive University Relationships Help Companies Find Bright Engineering Graduates", IEEE Power and Energy Magazine, Jan/Feb, 2005, pp 34-37.
7. D. Ray, and F. Wayno, "Collaboration to Facilitate Research and Education in a Transitioning Electric Power Industry", International Energy Journal, Vol. 6(1), Part 4, June 2005, pp 4-151 to 4-164.
8. R. E. Fehr, "A Model Curriculum for Power Engineering", 2008 IEEE Power Engineering Conf., pp.1-5.
9. R. Belu, F. Lacy and L. I. Cioca- Electrical Energy Engineering Education for the 21st Century, Journal of Higher Education Theory and Practice, Vol. 20(11), pp. 112-123, 2020
10. F. Kjersdam and S. Enemark, *The Aalborg Experiment: Project innovation in university education.* Aalborg, Denmark: Aalborg Univ. Press, 1994.
11. C. L. Dym, A. M. Agorino, O. Eris, D. D. Frey, Engineering design thinking, teaching and learning, Journal of Engineering Education, Vol. 94(1),, pp.103-120, 2005.
12. A. Yadav, et al. Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course, *Journal of Engineering Education,* Vol. 100(2), pp. 253–280, 2011.
13. J. Strobel, and A. van Barneveld, When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms, Interdisciplinary Journal of Problem-based Learning, 3(1), pp. 44–58, 2009.
14. F. Blaabjerg, A power electronics and drives curriculum with project-oriented and problem-based learning: a dynamic teaching approach for the future, Journal of Power Electronics, Vol. 2(4), pp. 240-249, 2002.
15. J. Macias-Guarasa, J. M. Montero, R. San-Segundo et al., "A project-based learning approach to design electronic systems curricula", IEEE Transactions on Education, Vol. 49(3), pp.389-397, 2006.
16. L. R. J. Costa, M. Honkala, A. Lehtovuori, "Applying the Problem- Based Learning Approach to Teach Elementary Circuit Analysis", IEEE Transactions on Education, Vol. 50(1), pp. 41-48, 2007.
17. J. R. Savery, "Overview of problem-based learning: Definitions and distinctions," Interdiscipl. J. Problem-Based Learning, vol. 1, no. 1, pp. 9–20, 2006.
18. A. Mantri , S. Dutt , J. P. Gupta and M. Chitkara "Design and evaluation of a PBL-based course in analo electronics", IEEE Trans. Educ., Vol. 51, no. 4, pp.432-438, 2008.
19. A. Nonclercq, A. V. Biest, K. D. Cuyper, E. Leroy, D. L. Martinez, and F. Robert, "Problem-based learning in instrumentation: Synergism of real and virtual modular acquisition chains," IEEE Trans. Educ., vol. 53, no. 2, pp. 234–242, May 2010.
20. M. M. T. Valdez, C. I. F. Agreira, C. M. Ferreira, and F. P. M. Barbosa, "Lighting design course in an electrical engineering program using problem-based learning," in Proc. EAEEIE Annu. Conf., Valencia, Spain, Nov. 2009, pp. 1–6.

21. R. H. Chu, D. D. Lu, and S. Sathiakumar, “Project-based lab teaching for power electronics and drives,” IEEE Trans. Educ., vol. 51, no. 1, pp. 108–113, Feb. 2008.
22. J. E. Mitchell, B. Canavan, and J. Smith, “Problem-based learning in communication systems: Student perceptions and achievement,” Development, vol. 53, pp. 587–594, 2010.
23. F. Martinez, L. C. Herrero, and S. de Pablo, “Project-based learning and rubrics in the teaching of power supplies and photovoltaic electricity,” IEEE Trans. Educ., vol. 54, no. 1, pp. 87–96, Feb. 2011.
24. H. Jackson, K. Tarhini, B. Maggi and N. Rumsey, “Improving Students Understanding of Engineering Concepts Through Projects Based Learning,” IEEE Frontiers in Education Conference, pp. 1-6, 2012.
25. A. Hren, M. Milanovic and F. Mihalic, “Teaching magnetic component design in power electronics course using project based learning approach”, Journal of Power Electronics, Vol. 12(1), pp. 201-207, 2012.
26. D. Santos-Martin, J. Alonso-Martínez, J. Eloy-Garcia Carrasco, and S. Arnaltes, “Problem-Based Learning in Wind Energy Using Virtual and Real Setups”. IEEE Trans. Educ, Vol. 55(1), 2012, pp. 126-134.
27. F. J. Maseda, I. Martija, and I. Martija, “An Active Learning Methodology in Power Electronic Education”, 2014 IEEE Frontiers in Education Conf. (FIE) Proceedings, 22-25 Oct. 2014, DOI: 10.1109/FIE.2014.7044082
28. R.G. Belu, “A Project-based Power Electronics Course with an Increased Content of Renewable Energy Applications”, June 14-17, 2009 Annual ASEE Conference and Exposition, Austin, Texas (CD), 2009.
29. D.G. Lamar, P. F. Miaja, M. Arias et al., “A Project-Based Learning Approach to Teach Power Electronics”, 2010 IEEE EDUCON Education Engineering Conf., Madrid, Spain, 2010 (CD).
30. A. Martinez-Mones, E. Gomez-Sanchez, Y.A. Dimitriadis, I.M. Jorrin-Abellan, B. Rubia-Avi, G. Vega-Gorgojo. Multiple Case Studies to Enhance Project-Based Learning in a Computer Architecture Course. IEEE Trans. on Education, Vol. 48(3), pp. 482-489, 2005.
31. N. Hosseinzadeh, and M. R. Hesamzadeh, “Application of Project-Based Learning (PBL) to the Teaching of Electrical Power Systems Engineering”, IEEE Trans. Educ, Vol. 55(4), 2012, pp.495-501
32. R. Belu, “Renewable Energy Based Capstone Senior Design Projects for an ET Curriculum”, 2011 ASEEE Conference & Exposition, June 26 - 29, 2011, Vancouver, BC, Canada (CD).
33. B. Warin, O. Talbi, C. Kolski, and F. Hoogstoel, “Multi-role project (MRP): A new project-based learning method for STEM”, IEEE Transactions on Education, Vol. 59(2), 2015, pp. 137-146.
34. B Warin, C Kolski, M Sagar, “Framework for the evolution of acquiring knowledge modules to integrate the acquisition of high-level cognitive skills and professional competencies: Principles and case studies”, Computers & Education, Vol. 57 (2), 2011, 1595-1614.
35. B Talon, C Toffolon, B Warin, “A university project: Towards Web-assisted collaborative management”, International Journal of Technologies in Higher Education, Vol. (2), 2005, pp. 28-33.
36. J. Macias-Guarasa, J. M. Montero, R. San-Segundo et al., “A project-based learning approach to design electronic systems curricula”, IEEE Transactions on Education, Vol. 49(3), pp.389-397, 2006.
37. D. G. Lamar, F.F. Miaja, M: Arias et al., “Experiences in the application of project-based learning in a switching-mode power supplies course,” IEEE Trans. Educ., Vol. 55, no. 1, pp.69 -77, 2012.
38. Z. Zhang, C. T. Hansen, and M. A. E. Andersen, “Teaching Power Electronics with a Design-Oriented, Project-Based Learning Method at the Technical University of Denmark”, IEEE Transactions on Education, Vol. 59(1), pp.32 -38, 2016.
39. R. Belu, “Project-based Teaching Approach of a Combined Undergraduate and Graduate Course in Power Electronics”, 2019 ASEE Annual Conference and Exposition, Tampa, Florida, June 16-19, 2019 (CD).
40. B. Warin,, “Description of the Multi-Role Project method (International version),” Internal publication of the University of Littoral Côte d'Opale, France, 2012. Available http://mepulco.net (accessed June, 2019).
41. B. Warin, F. Hoogstoël, “Multi-Role Project methodology - Educational Progress,” Internal publication of the University of Littoral Côte d'Opale, France, 2013. Available: http://mepulco.net (accessed June, 2019).
42. I. Hassan, "The importance of role clarification in workgroups: effects on perceived role clarity, work’s satisfaction, and turnover rates", Public Administration Review, Vol. 73(5), pp. 716-725, 2013.