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Provision of the practical learning environment via application-based projects integrated with the undergraduate engineering curriculum.

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I. Introduction

The undergraduate engineering curriculum forms the fundamental knowledge base for our future engineers who would be serving the global society. It is imperative for the undergraduate engineers to get a reality check on the utility of their classroom knowledge that would help them shape their career path and would provide them a valuable appreciation of the course content. Phylis Blumenfeld et al. [1] emphasized on the compelling argument of making projects an integral part of the learning process, as they promote student motivation, thought, and prove to be a potentially important learning tool. They underlined the role of technology as a contributor to variety, challenge, means of interaction, generation of artifacts, physical and intellectual accessibility of information. J. Hawkins et al. [2] however pointed out the need of presenting scientific enquiry in a way that the students learn to develop questions and problems, recognize their own ideas and knowledge-states, learn to explore the consequences of alternative ideas, and juxtapose and try out interactions of this new information with their own beliefs. S. Bell [3] suggested the application-based projects as a targeted tool that is guided by an inquiry question that drives the research and allows students to apply their acquired knowledge. This paper also acknowledged the use of real world projects as applications since these tasks run the gamut in terms of necessary skill. O. Erstad [4] also indicated the significance of incorporating real-life applications in the curriculum and describes them as a part of the learning situation that becomes more relevant to the students. It also suggested that tearing down the mental and physical barriers of the classroom brings the real world directly into the classroom learning environment while creating an expanded community of practice. The students end up developing a broader comprehension of the course content and how it has application and meaning outside the boundaries of the classroom.

C.E. Hmelo et al. [5] outlined the essential requirement of the application-based projects in complex tasks and learnings, as it requires scaffolding to help students engage in sense-making, managing their investigation & problem-solving processes, and encouraging them to articulate their thinking, while reflecting on their learning. However, a completely different perspective in terms of fighting social stigmatization among students, using application-based projects was presented by K. Koutrouba et al. [6]. They held the application-based projects responsible for the successful acquisition of skills such as persistence, willingness, cooperativeness, creativity and self-starters, while the student's personal experiences, traits, needs, interests and objectives were engaged but subordinated to social, cooperative objectives and expectations, during the process of the project. This perspective helped in the realization of the important aspect of the overall development of learners through application-based projects, beyond their academic performance, in areas of determination, adaptability, helpfulness, affective maturity, self-confidence, self-knowledge, inventiveness, resourcefulness, creativity, imagination, sociability and openness. V. Ryzin et al. [7] also heightened the consequence of the application-based projects by underlining its role in allowing the participants to actively use their personal-life experiences and the opportunity to constructively put the combination of their life and university experiences to the best use. As educators, it is expected of us to equip our students with the essential technical expertise needed to excel in their professional career, but also make them experts at application of their classroom knowledge smartly throughout their lifetime. K. Gary [8] makes a strong statement about the repeated, sustained team interactions on complex scalable problems that require constant synthesis and application of core computing concepts throughout the curriculum, being able to place students on a trajectory towards becoming professional engineers. Application-based learning usually culminates into an end product, as a solution to a driving engineering question, which creates a more compelling motivation among the students to willingly take up the approach, The freedom that students experience in becoming independent problem-solvers by applying their knowledge to relevant projects provides them the boost in their confidence for tackling challenges and value optimism in achieving solutions. Hence, application-based projects are a reliable tool for the overall development of the students in a learning environment.

II. Application Based Projects

The need for the inclusion of the application-based projects in the engineering curriculum, is best described by a popular quotation: "***Tell me and I forget, Teach me and I remember, Involve me and I learn.***"
The aim of this paper is to establish the role of the integration of application-based projects in the engineering curriculum, so that students end up becoming sharper researchers, thinkers of higher-order and confident problem solvers. This pedagogy primarily promotes motivation among students, while giving them an opportunity to demonstrate their in-depth knowledge and meet the expectations in challenging academic / professional situations. It also provides the university a chance to communicate and connect with the industries relevant and pertinent to the disciplines offered in their College of Engineering. The integration of application-based projects in the engineering curriculum would also encourage the fading away of the classroom management issues faced by the instructors, given the students would be focused and driven towards their respective active projects. S. Cocco [9] attempted to put the application-based projects in a framework of definition, that suggested this learning technique based on three constructivist principles: learning is context-specific, learners are involved actively in the learning process and they achieve their goals through social interactions and the sharing of knowledge and understanding. M. Cachia et al. [10] redefines the academic success of the students from their perspective, which indicates that the students are not only on a look out for accomplishing the subject knowledge, but also in developing employability skills. It was established from their work that accomplishing academic success and minimizing skill gaps for employability post qualification, requires the soft skills, like motivation, self-directed learning and confidence, as primary elements as part of the college degree program. E. Pang et al. [11] investigated the competencies (Ability and willingness to learn', 'teamwork and cooperation', 'hardworking and willingness to take on extra work', 'self-control' and 'analytical thinking') effectively needed for fresh graduates to succeed at work and they found the earnest need of developing these competencies among university students prior to their entry into the workforce. It is clear from these studies that the skillsets needed to succeed respectively in university and in the professional career have an overlap, but they indicate a requirement of more than the basic course content knowledge, and an obvious need for application-based projects. Hence it is evident that purely technical skills are insufficient to translate intellectual output to real-life applications and industrial products.

A. *Project characteristics*

The application-based projects should enhance the learning process and must be in sync with the engineering course content. This pedagogy demands certain attributes in the choice of the application and eventually the project, that cultivates student's creative ability in innovation and problem-solving. J.W. Thomas [12] identified the five essential characteristics of a well-rounded project, which are, Centrality, Driving questions, Constructive investigations, Autonomy and Realism. The application-based projects should be given a central position in the engineering curriculum, where illustrations, examples and experimentation would be the key techniques for teaching the course content, that would eventually lead to the better retention of the content taught in the classroom. P. Blumenfeld et al. [1] argued to choose applications that would drive the students to encounter the vital concepts and principles of the engineering course, while simultaneously ensuring that the students are in service of an important intellectual purpose, during the duration of the project. Students must be able to investigate the subject matter to inspire their creative and critical thinking. An application driven problem, that can be solved with the already learned classroom knowledge, then it ends up being an exercise and not an application-based project, which makes enquiry, a critical attribute of an engineering project. J. Krajcik et al. [13] indicated with their findings that the inquiry process made the students thoughtful in designing investigations and in planning procedures. The projects are student driven, so there is a better shot at the project success, when the problem statement is genuinely original, and solution to that problem has the potential to be directly implemented in a real-life application. W.E. Blank et al. [14] discusses the concept of real-life and how the application-based projects act as a window into the adult life of the students. They focused their findings on the academic skills and knowledge used in most workplaces and examined how graduates learn as adults via planning, discussion and project-implementation that have real world impact.

B. *Methods Explored – An Example*

The standard procedure to implement project-based learning is to provide a complex question for an extended period of time and allow the students to investigate an appropriate and meaningful solution, while simultaneously learning the tools needed [in their regular coursework] to arrive at the solution. I chose the following problem for a freshman engineering course based on basics of programming languages.

PROBLEM STATEMENT: "The 10-member student design team will be responsible for designing, building and testing a prototype machine for the delivery of water treatment pellets [aka the Marble Sorter], in 4 months. This project is part of the project headed by the World Health Organization to stop an outbreak of Ebola hemorrhagic fever."

DESCRIPTION: WHO proposed a 3- pronged attack

- Quarantine the disease-affected area to limit the spread of the disease/
- Introduction of antivirals into water wells
- Treatment of female macaques to reduce their population over a long time.

The team needs to develop a proof-of-concept unit that will introduce the antivirals along with appropriate chemical treatments to improve the water quality into a well at regular intervals. To reduce exposure time to the disease, mixtures of pellets will be delivered in a single container.

RESOURCES PROVIDED: LabVIEW, MATLAB, Lego Kit, Barcodes

DELIVERABLES: There will be 3 in-class demos prior to the final in-class demonstration.

- Read the bar code from each of four cards and determine the pellet mix specified by those four cards. All four cards [barcodes] should be read and the pellet mix determined before any pellets are delivered into the well.
- Receive an unsorted mixture of approximately 75 pellets.
- Sort the pellets by size, color, and material.
- Gather the correct dosage as specified by the bar codes. This involves gathering the needed pellets from the pre-sorted pellet bins.
- If a **complete** correct dosage can be gathered, deliver the mix of pellets into the well. A complete set of the pellet mix must be introduced into the well **three times** over a ten minute period with a minimum of a twenty second gap between deliveries.
- If there are insufficient pellets available for the specified mix, no pellets should be dispensed, and an alarm signal provided.
- The final unit is expected to be solar powered. Therefore, you should be as energy efficient in your design as possible.

This project required the students to utilize their knowledge on programming languages [LabVIEW and MATLAB], which they were learning during the 4 month period and simultaneously implementing it in their semester long project. This allowed the students to appreciate their classroom leaning & promoted self-directed learning. The students majorly felt a boost in their confidence based on their ability to inquire, investigate, and apply their newly acquired algorithmic thinking capabilities into relevant projects creating a positive impact in the society. I was pleasantly surprised at the variety and creativity in the solutions offered by various student teams and the discipline showcased by the students, who systematically followed the instructions and delivered the protype in accordance with the engineering specifications.

C. *Challenges in implementation of application-based projects*

The successful execution of the pedagogy dealing with the inclusion of application-based projects is dependent on a variety of factors such as instructors, students, administrators, classroom resources, external factors, troubleshooting, collaborative work-environment, etc. The systematic agreement of all factors will lead to the successful completion of the application-based project, which automatically suggests that any disagreement of the above-mentioned factors can pose to be a challenge in the implementation of the project. Although this pedagogy is expected to trigger student's motivation and critical thinking ability, some researchers have found contradictory findings during the implementation of the application-based projects. D. H. Dolmans et al. [15] observed that students maintained the appearance of active involvement in the projects, by doing superficial and minimal work through making inadequate connections between new information and prior knowledge. They also emphasized on the problem with the instructors choosing familiar solutions from their own professional training and showcased the possibility of adopting actions consistent with the student-directed view of education in application-based projects. J.H.C. Moust et al. [16] showcased several issues among students as well as instructors that pose as a bottleneck to the successful implementation of the application-based projects. Figure 1 demonstrates the cognitive processes in the application-based project learning environment, as it reflects the expected flowchart of the project completion, from start to finish. However, it was observed contrary to the expectations that the students would depend on tutor-guide and would keep their workload minimal as guided by the tutor-guide, thereby completing neglecting any form of engagement in the inquiry investigation of the problem. The factors that led to this student-behavior were analyzed and listed as insufficient study-time, minimal preparation prior to tutorial group study sessions, insufficient time devoted to literature review, superficial synthesis of investigation and possible omission of any form of brainstorming. They also established a few shortcomings among some instructors who would provide a specific list of learning resources instead of a long list of potential resources that would encourage the students to research and evaluate the applicability of the resources to the application-based project. D. Taylor et al. [17] reported their findings on the student's lack of motivation and effort to engage in the cognitive process that led to the challenge of being able to maintain their interest in the subject matter while hindering the realization of the true potential of application-based projects as a whole-of-curriculum concept.

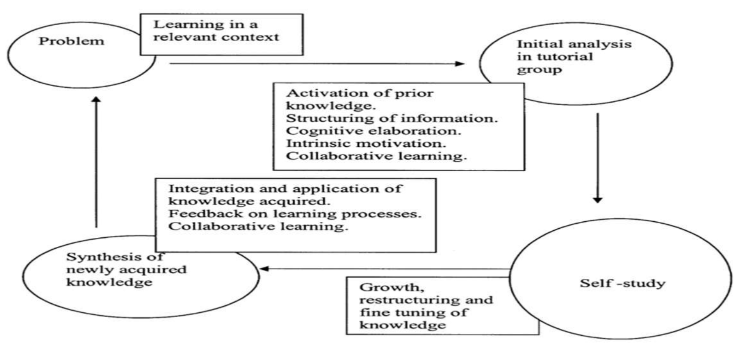

Figure 1: Schematic of the cognitive processes in the application-based project learning environment. [16]

Unavailability of essential resources and the demanding deadlines on the workload can also be a potential challenge to the effective implementation of the application-based projects. I. Vardi et al. [18] projected the drawback of the provision of insufficient time for project completion, due to the strict timeframe of the semester. The instructors as well as students apparently had issues with the workload and the demand on time for completing the required tasks. Their work recommended a bunch of solutions to combat this issue by providing computer-supported projects, online resources, listing key-conceptual questions, guiding students towards fruitful discussions, provision of the grading rubric with outlined criteria, and performance-based assessment. R. Schultz et al. [19] indicated the inclusion of the application-based projects in the regular curriculum is a slow process in terms of smooth acceptance from the students. The uncertainty of the expectations from the students in the transition from regular lecture-based classrooms to learning via application-based projects, could lead to apprehensions among them.

III. ENERGIZING THE UNDERGRADUATE EXPERIECNE

Irrespective of the challenges in implementing the application-based projects in the engineering curriculum, there is no doubt in the fact that it provides the necessary exposure needed for the future professional success. The undergraduate students receive hands-on experience and get a chance to showcase their knowledge via product creation through the application -based projects. They develop the ability to become independent thinkers and decision-makers. This particular pedagogy focuses on the learning outcomes of the course and promotes the students to reflect on the course content taught in the classroom. The industry has seen a recent team-based organizational structure in their workforce, which prompted the universities to adopt application-based projects similar to the industrial setup. In order to ensure a great experience for the undergraduate students, instructor, the industrial client or any other stakeholders associated with the project, it is essential to execute well-informed decisions towards project identification, design elements, course content, evaluation criteria, student team structure, etc. These factors would help enhance and energize the already existing fruitful undergraduate engineering experience.

A. Encouraging undergraduate students to become self-directed learners

The initial performance of the undergraduate students in the application-based projects is based on their prior knowledge and training to act as self-directed learners. B.M.Miflin et al [20] have described the self-directed learners as someone who are able to identify the shortcomings in their own knowledge & skills and are motivated to generate a learning program for addressing the shortcomings, have the skills to identify, access and use resources wisely, while having a sharp sense of evaluation of the learning efforts. In the application-based projects, the students are encouraged to generate learning objectives defined by the instructor as per the course syllabus. There could be multiple features to this approach as follows:

- An overview of the syllabus helps the students see the relevance of current learning to the bigger picture of the learning outcomes.
- The students seek guidance throughout their participation in the application-based projects, but they end up becoming improved versions of themselves, as self-directed learners, by being the curriculum for longer time and thus becoming more experienced, as observed by D. H. Dolmans et al. [21].
- The undergraduates also develop an appreciation in the overall curriculum, when they see the relevance of the application-based projects aligned with their professional goals, and their growing confidence in the tutorial process enables them to become better self-directed learners.
- The students develop a deep understanding of the application-based project learning model, based on the thorough design of the engineering curriculum.
- The undergraduates are encouraged through the application-based projects to acquire new knowledge built on prior knowledge, from a variety of appropriate resources.

All the above-mentioned bullet points indicate self-directed learning as a powerful tool that leads to students becoming responsible learners over the semester, while reducing the dependance on the expected instructions from the instructors.

B. Adopting new assessment techniques

The evaluation techniques have a major influence on the student’s learning strategies. The assessment techniques should be designed in a way that would encourage students to remain focused in their learning process and feel the enthusiasm and joy to continue learning in the hope of a better grade. There should be several stages of grading throughout the semester for the application-based projects, so that students remain engrossed in the projects with short-term goals while keeping their focus on the end product. Multiple grading stages, also allow students to become disciplined in terms of maintaining deadlines and completing the workload within the expected duration. The evidence of progress must be regularly monitored and recorded. The evaluation can be based on several criteria ranging from the processes utilized throughout the project, the new acquired knowledge used in combination with the prior knowledge, team effort, progress to achieve the learning outcome. The instructors need to be vigilant through personal observations to ensure the development of soft skills in the individual students, as they are difficult to assess via paper-based tests. A team charter developed among the team-mates as a contract, can help assess the soft skills among students. The final presentation of the projects and the perspective of individual students in applying the knowledge towards real applications is also an alternative evaluation tool of the skillsets developed in the undergraduate students during the different stages of the application-based projects.

C. ***Developing projects compatible with available technological resources.***

The availability of resources makes the learning process smoother. The absence of any essential resource has the power to curb the student enthusiasm and eventually leads to an average project outcome. Technology-enhanced learning methods provide an organized structure in effectively comprehending the multiple stages of application-based projects. Designing projects compatible with the current software, hardware, advanced data-processing techniques, etc. allow students to keep up with the current industrial pace in the real-workspace environment. The generated results and data derived via the use of various software tools, provide essential feedback towards the successful progress of the project. This new project designed with the help of latest technology encourages the learner's desire for accomplishment and willful engagement in the learning process. However, it is true that articulating a combination of technologies can ease the learning process, but certainly does not guarantee the successful completion of the project.

IV. CONCLUSION

It is essential for the instructors to re-examine their strategies while assigning application-based projects, as they are becoming a second-nature in the team-based organizations and industries. This paper explored the various factors that can maximize the student learning through the utilization of application-based projects. This pedagogy promotes collaboration and creativity among students, despite the challenge of assessing formatively and summatively respectively. The benefits of the application-based learning are more durable and most certainly helps in better retention of the course content. A certain level of autonomy and ownership of their project, makes the students develop the habit of taking control of their own learning, while the repeated team interactions on the problem statement that require the application of core concepts and through research, force the students to automatically become professionals in their deliverables. The positive outcomes of integrating application-based projects in engineering curriculum, include enhanced professionalism, self-reliance and improved attitudes towards classroom learning.

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