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Delivery of Aircraft Design Curriculum through Problem-Based Learning Approach

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Abstract

Aircraft Design is a multidisciplinary subject. It requires knowledge in the subject areas of aerodynamics, structures, propulsion, stability and control, to name a few. Many universities in the United Kingdom teach aspects of Aircraft Design, as a part of the Aeronautical Engineering curriculum, in the final year of their degree programme. By this stage, the students have acquired basic skills in the fundamental aeronautical science. The methodology of teaching Aircraft Design, which has been applied for undergraduate aeronautical engineering students for many years, is based on Problem-Based Learning (PBL) methodology. It is a concept used to enhance multidisciplinary skills using planned project scenarios. In this methodology, students work in small collaborative groups and learn what they need to know in order to solve a problem. In this paper the role of PBL is examined in delivering Aircraft Design as a PBL scenario.

I. INTRODUCTION

Aeronautics is defined as the science of operating aircraft. It is concerned basically with predicting and controlling the forces and moments of an aircraft travelling in the air (McCormik, 1995). Engineering is the practice of applying scientific knowledge to the design, construction, and operation of machines and instruments. Engineering design is the process of devising a feasible and efficient solution to some specified needs. It is a complex process of creative and analytical steps, where basic and engineering sciences are applied to convert resources into real products (Ertas & John, 1993). The designer is required to solve an ill-defined problem to reach the best (or one of the best) among the many possible solutions.

The philosophy of aeronautical engineering course is that knowledge, understanding, and

skills needed for aircraft operation and design are best acquired through interdisciplinary teaching and demanding application, rather than through a disjointed series of individually assessed modules (Stocking, 2007). ‘Aircraft Design’ is a multidisciplinary subject. It requires knowledge in the aerodynamics, structures, propulsion, stability and control. Therefore, ‘Aircraft Design’ is deemed to be a mandatory part of any aeronautical engineering curriculum.

“It is the corner stone of the aeronautical engineering syllabi. It is recognised as a science that educates the student in synthesis perspective and contributes to create in the future professional an open mind mentality”, (Martinez-Val & Perez, 2008).

Many universities in the United Kingdom teach aspects of aircraft design, as a part of the Aeronautical Engineering curriculum, in the final year of their degree programme. By this stage, the students have acquired basic skills in the fundamental aeronautical science. On the other hand, the present day concern of industry is that engineering students, in general, do not have the prerequisite skills to be effective practitioners. Hence, the researchers and academics have taken a note of this concern, and have evaluated methodologies that help students to become effective engineering practitioners. Two methodologies have been employed for teaching aircraft design; Problem-Based Learning and Project-Based Learning. So, the question is: which of them is the best way to teach undergraduate students Aircraft Design? Many universities follow a Problem-Based Learning methodology.

II. PROBLEM-BASED LEARNING (PBL)

Problem-Based Learning (PBL) is defined by Barrows, (Barrows & Tamblyn, 1980) as:

“The learning, that results from the process of working towards the understanding of resolution of a problem. The problem is encountered **first** in the learning process”.

Problem is something that cannot be resolved with the current level of knowledge and/or way of thinking about the issues. It is presented as an ill-structured as opposed to well-structured problem. It is characterized as a real-life and authentic, not a hypothetical exercise, messy not tidy, incomplete in the sense of lacking information needed for its solution and

iterative in the way that it produces further ideas and learning issues, (Stephen & Pyke, 1977).

The research has found that traditional educational approaches (e.g., lectures) do not lead to a high rate of knowledge retention. Despite intense efforts on the part of both students and lecturers, most material learned through lectures is soon forgotten, and natural problem solving abilities may actually be impaired. The motivation in such traditional classroom environments is also usually low.

One of the greatest advantages of PBL is that students genuinely enjoy the process of learning. The PBL methodology is a challenging programme because students are motivated to learn by a need to understand and solve real problems. The relevance of information learned is readily apparent; students become aware of a need for knowledge as they work to resolve the problems.

“It is vital that the problems are engaging, that they “smell real”, are interesting and challenging to students. This engagement stimulates further learning and requires research, elaboration, further analysis and synthesis together with decisions and action plans”, (Barrett, 2005).

This methodology of teaching Aircraft Design has been applied for undergraduate aeronautical engineering students for many years. It has become a widespread teaching methodology in disciplines where students have to apply knowledge not just acquire it, (Brodeur, Young, & Blair, 2002). The PBL approach is a concept used to enhance multidisciplinary skills using planned project scenarios. It is an active way of learning that teaches students problem-solving skills while at the same time allowing them to acquire basic knowledge. In this

methodology, students work in small collaborative groups and learn what they need to know in order to solve a problem. The students have to work as a team to manage the design process. They are presented with project before they have the skills and knowledge to solve it. The PBL methodology gives the students the opportunity to choose their peers according to effort and contribution made to the group project.

III. ROLE OF PBL IN TEACHING AIRCRAFT DESIGN

The summarised characteristics of PBL as stated by Yusof, (Yusof, et al., 2004) are obtained in the following with some detail, showing its role in teaching Aircraft Design:

- a) *A realistic problem, which captures the students' interest, is the starting point of learning.*

One goal of PBL is to help students become intrinsically motivated. Intrinsic motivation occurs when students work on a problem motivated by their own interests, challenges, or sense of satisfaction. Determining an appropriate problem for less skilled students requires that the problem designers understand what is developmentally appropriate, interesting to a heterogeneous group of students, and moderately challenging without being overwhelming, (Hmelo-Silver, Problem-Based Learning: What and How Do Students Learn?, 2004).

Furthermore, it is important to note that the problem serves as the basis for the learning process, because this determines the direction of the learning process and places emphasis

on the formulation of a question rather than on the answer. The problem should be related to the context, which promotes student motivation and comprehension, (Graaff & Kolmos, 2003).

In Aircraft Design, the problem usually is based on real-life problems which has been selected and edited to meet educational objectives and criteria. For example, the problem could be to design a 140 passenger jet with a range of 1500 nautical miles, which has minimal noise emissions and cheaper than the existing operational aircraft in terms of direct operating costs.

- b) *The project challenges students' existing knowledge, attitudes and competencies, leading them to identify problem new knowledge (or learning issues) needed, and shortcomings that need to be corrected.*

The main feature of PBL problems is that they are incomplete in the sense of lacking information needed for its solution and iterative in the way that it produces further ideas and learning issues, (Stephen & Pyke, 1977). Discussing problems in a PBL group, before beginning to research learning issue, activates relevant prior knowledge and facilitates the processing of the new information.

Students formulate and analyse the problem by identifying the relevant facts from the project scenario. This fact-identification step helps students represent the problem. Once the students understand the

problem better, they generate hypotheses about possible solutions. Identifying knowledge deficiencies is an important part of this cycle. These knowledge deficiencies become what are known as the learning issues that students research during their self-directed learning.

In Aircraft Design, students will need to find out the capabilities of existing solutions, and determine the important design issues that need to be tackled. In order to understand the problem fully more in depth knowledge needs to be gained. And areas of knowledge deficiency need to be identified.

- c) ***The responsibility and direction of learning is assumed by the students. Faculty members are only there to facilitate students' thinking, learning and group functioning to help them resolve any problem.***

Students must be able to set learning goals, identifying what they need to learn more about for the project they are engaged in. They must be able to plan their learning and select appropriate learning strategies. Once students implement their plan, they must be able to monitor and evaluate whether or not their goals have been attained, (Hmelo-Silver, Problem-Based Learning: What and How Do Students Learn?, 2004). A typical aircraft design problem scenario is broken down into: Aerodynamics, Propulsion, Stability and Control, Structures, Materials, Manufacturing, Project Management, Systems and Avionics. Each member in the team

must pick a sub-speciality of his or her interest, so that effective contributions could be made throughout the span of the project.

On the other hand, faculty members (or so-called facilitators) guide the students in the learning process, pushing them to think deeply, and model the kinds of questions that students need to be asking themselves, thus forming a cognitive apprenticeship. The facilitators make key aspects of expertise visible through questions that scaffold student learning through modelling, coaching, and eventually fading back some of their support. The role of facilitators is critical, as they must continually monitor the discussion, selecting and implementing appropriate strategies as needed. In PBL, the facilitators should be expert learners, able to model good strategies for learning and thinking, rather than providing experts in specific content, (Hmelo-Silver & Barrows, Goals and Strategies of Problem-Based Learning Facilitator, 2006).

- d) ***Information mining from various sources, and utilization of evaluation to analyse what is really useful.***

The problems in the PBL methodology challenge the students' prior knowledge and motivate them to search for new information that has not been learned before. It may not be available in their curriculum lectures or textbooks. The necessity of gathering knowledge from a wide range of sources allows students to see how knowledge is a useful tool for

problem-solving. It gains students the research skills such as how, where, and when they find the solution to a certain problem.

In Aircraft Design, once the specialist roles have been assigned in the group, the individual has to seek information from various sources, namely books and journals and the e-media. The student must sift through information and identify the relevant and pertinent material that may be applicable to the problem in hand.

e) The process of identifying learning issues and problem-solving is as important as acquiring new knowledge to arrive at the solution.

Another feature of PBL problems is that they are “ill-structured”. This feature is used to describe open-ended problems that have multiple solutions and require students to look to many methods before deciding on a particular solution. It helps students learn a set of important concepts, ideas, and techniques because they motivate group discussion and give students experience solving problems encountered by experts in the field. Students recognise these problems as professionally relevant, (Gallagher, 1997). As a result of that, students are more likely to be motivated to work on them (as opposed to discrete problem sets or textbook exercises) not only because they realise that the knowledge they gain by thinking about these problems will be useful in the future, but also because they are typically given significant opportunities for creativity and

flexibility in solving PBL problems, (Learning, 2004).

In general, the PBL is an effective methodology for improving students’ problem-solving skills. When students learn facts and skills by actively working with information rather than by passively receiving information, they will make strong connections between the concepts, (Gallagher, 1997). However, not only the knowledge deficiency is to be identified but new material needs to be learned, some of it might come during the normal classroom contact with the facilitators, other needs to be learned independently.

Facilitators who provide a good learning community in the classroom, with positive facilitator-student and student-student relationships, give students a sense of ownership over their learning, develop relevant and meaningful problems and learning methods, and empower students with valuable skills that will enhance students’ motivation to learn and ability to achieve, (MacKinnon, 1999). The PBL methodology promotes students’ confidence in their problem-solving skills and strives to make them self-directed learners. These skills can put students at an advantage in future courses and in their careers.

f) Students learn in cooperative teams, where they need to interact and communicate to share knowledge, discuss their understanding and debate conflicting opinion.

Weekly meetings are normally held by the students, in the presence of the facilitators, where the individual contributions are discussed. The nature of the dialogue is a process by which students together create and recreate knowledge as

“true dialogue unites subjects together in the cognition of the object that mediates between them”, (Freire, 1985).

For instance, if the aerodynamicist were to increase the wing area, it will have impact on other disciplines, due to weight increase. Keeping the design focused on the objective requires effective communication, failure to do so will result in a design that may not be feasible. On the other hand, in the PBL, students are constructing their own knowledge together. Weekly meetings contrast with individual research. The individual research was seen in terms of my knowledge and control, whereas the weekly meeting was seen in terms of our knowledge and control. One student discussed this issue;

“Philip: Well, my opinion on the idea of the PBL working in groups, if I was working independently I couldn't have been as creative as this group has been. And the number of ideas that

were thrown around and developed by the group is very, very, I think it creates a whole new dynamic. Whereas if I work independently I am sure for everyone here, independently, they wouldn't have felt it was as creative a process or as interesting a process, I think”, (Barrett, 2005).

g) *Synthesis of various knowledge and information to arrive at the solution.*

The synthesis and investigation is one of the goal-directed processes of the PBL methodology. This may be component design, design variable estimation, problem-finding, or model-building processes. These processes sometimes represent difficulty to the students that can't be carried out with the application of already-learned information or skills. However, students must pursue their study in a way which requires that they gain a realistic sense of why certain problems are or can be, seen as sufficiently important to justify inquiry into them, of how this inquiry proceeds, and of how to evaluate the knowledge gained through inquiry.

It is expected that students may reach a level of analytically complex comprehension through the problem-based work that would not be possible in conventional classes. Information and learned knowledge must be

critically reviewed so that the relevant ones can be synthesised and applied to solve the problem. Facilitators must ensure that the coverage of problem is sufficient, and probe students on accuracy and validity of the information obtained. Needless to say, students have to verify the design through simulation and numerical computation. This hones their numeracy skills, and gives them the feel for numbers.

h) Reflection of the students' learning experience.

The solution of the problem is presented to the class, followed by more probing questions by the facilitator to ensure deeper learning. Students reflect on what they have learned, how well they collaborated with the group, and how effectively they directed their learning. The reflection process in the PBL methodology is designed to help students identify gaps in their thinking, transfer their problem-solving strategies, and transfer their self-directed learning strategies.

“Reflection helps students (a) relate their new knowledge to their prior understanding, (b) mindfully abstract knowledge, and (c) understand how their learning and problem-solving strategies might be reapplied”, (Hmelo-Silver,

Problem-Based

Learning: What and How Do Students Learn?, 2004).

On the other side, the PBL assessments should be authentic. They should be structured so that students can display their understanding of the problem and their solution in contextually-meaningful ways. It is clear that multiple-choice assessments and even short-answer or essay questions, which require rote repetition of facts, will be of little value in assessing the extent to which students have internalised holistic approaches to complex problems. The feedback students receive from their peers is a critical part of the assessment in PBL methodology.

The facilitator may ask students to rate their group members using a numerical scale based on ‘attendance, degree of preparation for class, listening and communication skills, ability to bring new and relevant information to the group, and ability to support and improve the functioning of the group as a whole’. These peer ratings are not sufficient feedback. The facilitator should also provide detailed comments about each student’s strengths and weaknesses. Having students evaluate their own performance can be a valuable task as well, (Learning, 2004).

IV. THE DESIGN PROCESS THROUGH PBL APPROACH

Aircraft design is a complex and iterative task. The delivery of the necessary material and skills needed to achieve the desired objectives is usually not possible in the course of study, usually one or two semesters. Most universities present preliminary design projects as In-Course Assessment (ICA) for this reason, and as a PBL scenario. Students are sub-grouped into 5-8 students per team with the lecturer playing the role of facilitator. Teams are given a set of specifications for an aircraft to be designed (i.e. a problem). The specifications may include payload, speed, range, takeoff, landing performance, or specific mission objective, etc (i.e. requirements of the design). Students start searching with examples contained in aircraft design textbooks, or existing designs which may be available in e-media. With a hope to find a similar solution to their problem that requires only minimal amendments. Actually, these textbook examples are intended to show the way the design process may be applied to those who are starting to undertake aircraft conceptual design for the first time.

“It should be noted that these projects are not meant to provide a “fill in the blank” template to be used by current and future students working on similar design problems, but to provide insight into the process itself”, (Jenkinson & Marchman III, 2003).

In some cases, students may browse the internet searching for a computer code (program) that may help them with the initial variable selection that may meet their design objectives and how best to get final design

results. From the faculty view point, students should start the design process through reviewing their previous courses in aerodynamics, structures, propulsion, performance, etc.

Implementation of the PBL methodology in aircraft design starts with “Problem Overview”. Students have to read and understand the project scenario, organize their ideas, reflect and explain possible issues individually based on the available knowledge. Then, they have to identify the aspects of the problem and needs for research and literature review (learning issues). They are encouraged to do background reading on these issues. Subsequently, they sort the issues and plan when, who, where, how these issues will be investigated. During the initial few meetings, they share and explore the gathered knowledge about the learning issues and use them to propose an informed solution to the problem. They may have to restart the cycle if they cannot get a satisfactory solution. The team leader and the role of each individual in the team are decided at the end of this stage. The PBL methodology requires students to become responsible for their own learning. Students have the opportunity to develop skills in reasoning and self-directed learning, and be able to apply their knowledge to novel problems as well.

The second stage is “Conceptual Sketches and Analysis”. Students start by producing conceptual sketches of the proposed aircraft. The creative part of the design process, which has no rules and constraints, may produce neither logical nor illogical design alternatives. It is based on uncritical brain storming, observation of nature, and ideas from other engineering disciplines. Thereafter, these sketches are analysed separately depending largely on textbooks methods and single design is adopted by the team. Students may also identify appropriate existing knowledge and

more learning issues than those decided in the previous stage. At this stage, facilitators guide the students so that they are on the right track checking and questioning the learning issues identified.

The third stage is “Synthesis and Application”. Each student in the team starts to synthesise his/her own part (component) of the proposed aircraft. Final solution is an assembly of individual student contribution to the whole aircraft. Information is shared and critically reviewed so that the relevant ones can be synthesised and applied to solve the problem. Facilitators at this stage ensure that the coverage of the problem is sufficient, and continually probe students on accuracy and validity of the information obtained. This can be an iterative process, where students may need to re-evaluate the analysis of the problem, required further learning, reporting and peer learning. The outcome of this stage is the preliminary layout of the proposed aircraft is developed and an integrated report is produced which addresses not only the technical aspects of the design but also the financial viability of the concept, (Young, 2000).

The final stage is “Presentation, Reflection, and Assessment”. The designed aircraft is presented to the class and audience that may consist of practitioners of aircraft design working in industry, followed by probing questions to assess them and to ensure deeper learning. Other students are also asked to reflect on the content as well as the design. The facilitator helps with integrating knowledge

learnt from solving the problem with what they have already, and encourages students to give their opinion on the value and usefulness, of the proposed design, for future learning and application to the work place. The facilitator also summarizes crucial principles and concepts, as well as eliminates any doubts that arise from the students. **Figure 1**, (Al-Shamma, 2013) summarises the stages of implementing PBL process in Aircraft Design.

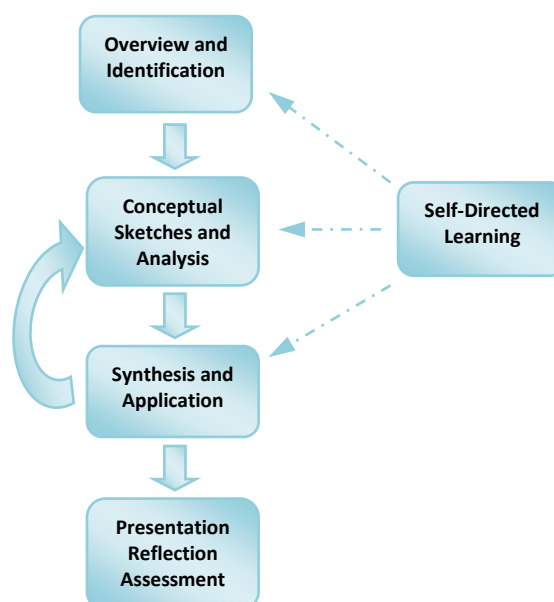


Figure 1: Framework of the PBL process in Aircraft Design, (Al-Shamma, 2013)

V. CONCLUSIONS

Problem-Based Learning (PBL) is a methodology in teaching and learning that can be applied successfully in delivering academic content to undergraduate aeronautical engineering students, especially, "Aircraft Design". The iterative nature of the design process and acquisition of knowledge by the students in trying to arrive at a feasible solution works well in the PBL scenario. The paper outlined the role PBL plays and the key elements that impacts on the students learning experience. The design process has embedded in it, many stages of reflection where after a preliminary and critical design reviews, students have an opportunity to improve their designs based on peer and facilitator feedback.

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