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Project-Based Learning – analysis and synthesis of mechanisms for awning window linkages

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ABSTRACT: In this article, the authors describe the project-based approach to teaching in the final year of a degree programme at the French Military Academy de St-Cyr in Coëtquidan, France. A project is the usual requirement in the final year of any degree programme in engineering. Since the Academy's training programme combines engineering education with military training, the cadets' preparation for their final year is different to that of students in a non-military university. In the normal system, a typical scenario of a *capstone* final year project is that it should require from the student an element of synthesis to combine knowledge from a few, or several courses in order to solve a particular engineering problem. However, in the case of cadets from the French Military Academy, the demand is not only on the project itself, but also on acquiring the necessary knowledge not covered in taught courses. The authors describe such an experience based on a project carried out by a student from the French Military Academy de St-Cyr in the Department of Mechanical Engineering at the University of Botswana in Gaborone, Botswana. The authors also describe the curriculum of an engineering programme at the French Military Academy de St-Cyr.

INTRODUCTION

A project is the most typical and fundamental requirement in the final year of any degree programme in engineering. It is sometimes called a *capstone* as it should require from the student an element of synthesis to combine knowledge from a few or several subjects in order to solve a particular engineering problem. Normally, it should be a design project or at least should have an element of design. Such a project is a typical requirement for the accreditation of an engineering programme.

However, is such a final year project really Project-Based Learning (PBL)? Although it carries certain elements characteristic of PBL, in reality, it is not full PBL. Students carrying out such final year projects are normally applying knowledge from different areas or courses that they have studied in their curriculum; but do they really acquire new knowledge through performing the project? If they do, then it is quite limited; they normally acquire some additional information on topics they have already studied.

A project is also part of the degree programme offered at the French Military Academy de Saint-Cyr (in full École Spéciale Militaire De Saint-Cyr). This well-known military school was founded in Fontainebleau in 1803 by Napoleon Bonaparte. In 1808, Napoleon moved it to the town of Saint-Cyr-l'École near Versailles. The buildings at Saint-Cyr-l'École were destroyed in 1944 during World War II, and after the war, the Academy was transferred to Coëtquidan in Brittany. Throughout most of its history, Saint-Cyr has prepared officers for the infantry and cavalry, as well as for staff positions within those services, while the École Polytechnique in Paris trained engineers, artillerymen and other technical officers. After World War II, however, the French Military Academy de St-Cyr took over the training of most technical officers.

CURRICULUM AT THE FRENCH MILITARY ACADEMY

The Academy's training programme meets the demands of the classic profile of the St-Cyr officer: to be leaders for the future [1]. The training is based on four tiers: general knowledge, values and beliefs, leadership potential and professional skills. General military training is the basis of officer training and focuses on three areas that are all complementary and interconnected: military conduct training, interdisciplinary academic training, and military and sports training. Interdisciplinary academic training has two distinctive elements: a detailed study of basic subjects that offer an educational background and general training, which provides the key to understanding the current environment. This general training includes subjects from the common core syllabus (like military history, history of international relations, French contemporary society, public law and communication) and specialised subjects depending on the background of each officer (for example human science and law for students in science, economics, statistics for science students).

The normal entry requirement is the completion of the preparatory school or the DES competitive examination. For such candidates, the programme consists of six semesters at the Academy, four based on academic training and two focusing on professional training. Semesters 3 and 4 constitute the elements required for a professional degree – specialised and optional courses in the chosen field of study. The training at the French Military Academy is as follows:

- Semester 1: integration;
- Semester 2: general training;
- Semester 3: specialised courses;
- Semester 4: optional courses;
- Semester 5: international placement;
- Semester 6: autonomy warfare training.

The training courses for cadet officers are recognised on an international level. All cadet officers from the Academy are awarded the St-Cyr Masters degree as cadet officers specialising in science in an engineering degree.

There are three academic departments that offer academic training programmes: the Department of International Relations, Department of Management of Organisations & People and Department of Engineering Science. The academic training programme forms a common core of the military training programme. Courses are taught jointly by the academic department and the Department of Military Techniques and Instruction, and also by outside professionals, a feature that underscores the all-rounded nature of the programme. This includes the following:

- Semester 2 focuses on basic and general knowledge courses that figure in all programmes in the three departments;
- Semester 3 concentrates on each respective specialisation;
- Semester 4 comprises advanced courses/optional courses of study or supplementary courses of study;
- Semester 5 is taken up by the work-placement abroad (duration 12 weeks), as well as preparation work and the completion of the thesis (four weeks).

The academic semester is made up of a 30-hour week. The remainder of the time is given over to sport and unscheduled courses. A 30-hour week (semesters 2 and 4) on average includes 20-24 contact hours plus personal research and self-study time, which brings the total number of hours up to 30.

The cadet officer who graduates in engineering science should possess excellent knowledge in science, be fluent in at least one foreign language (English) and have some experience in an international dimension. There are three specialisations: engineering physics, computing and simulations, and electronics and electromagnetism. Courses in the above streams provide the basis for the engineering project to be initiated in the 4th semester and completed in the 5th semester during the 12-week work-placement abroad. The core and stream courses are presented in Table 1.

THE PROJECT IN THE ENGINEERING CURRICULUM

An engineering project is initiated in the 4th semester and completed in the 5th semester during the 12-week work-placement abroad. The objectives are as follows:

- Involvement in research activities;
- Development of awareness of foreign cultures;
- Improvement of language skills.

The placement takes place in an academic establishment (normally a university or military academy). The work placement abroad takes an estimated 420 hours (considered as contact hours) plus 150 hours for work-placement preparation and completion of the report (considered as personal research and study). As the total number of contact hours for academic courses in the three-year programme is 2,065 (of which 1,347 hrs – 65.2% is dedicated to engineering courses), the project takes 14.5% of the total number of hours and 22.3% of engineering courses hours. That emphasises the importance of the project.

Another indicator of the importance of the project is the fact that its assessment constitutes 15% of the total mark for the programme. The above values of the percentage of time and component of the total assessment for the project is much higher than in ordinary engineering programmes at other universities. Hence, the question arises: why has so much credit been put into the engineering project?

Table 1: Curriculum at the French Military Academy.

Semester	Core Courses	Stream Courses		
		Computing & Simulations	Engineering Physics & Energy	Electronics: Communication & Detection
2	Mathematics (72 h) Physics (75 h). Engineering Physics (39 h) Electronics (31,5 h) Computing (34.5 h)			
3	Mathematics (39 h) Engineering Physics (70.5 h) Computing (75 h) Electronics (85.5 h)	Database design (24.5 h) Object-oriented Programming (49.5 h) Unix (46 h)	Mathematics (30 h) Analytical Engineering Science (40 h) Continuous Media & Theory of Elasticity (30 h) Thermodynamics (20 h)	Mathematics (30 h) Component Physics (22.5 h) Applied Physics Project (30 h) Controls of Electronic Systems (37.5 h)
4		Mathematics (30 h) Networks (30 h) Artificial Intelligence (24 h) Object-oriented Programming (70 h) Database and Project (50,5 h) Information Processing (60 h) Operational Research (34.5 h) Security of Information Systems (76 h)	Resistance of Material (65 h) Method of Finite Elements (60 h) Theory of Machines (70 h) Propulsion (45 h) Ballistics (45 h) Detonics (45 h)	High Frequencies & Antennae (55.5 h) Signal Processing (51 h) Signals & Systems of Communication (72 h) Radio Electric & Optic Connections (45 h) Radar (45 h) Optics, Laser Imaging (69 h) Research Project (37,5 h)

In order to answer the above question, it is necessary to look at the courses taught at the French Military Academy and their duration, and compare them with other engineering degree programmes. The normal strategy in an engineering curriculum is that the primary concern of engineering courses taught during the junior years is to provide students with a thorough understanding of the fundamentals. These courses should normally have strong applied mathematical and engineering science components. Moreover, after a good understanding of the basic principles and laws has been gained, the application of these fundamental principles for the design and analysis of practical problems should be introduced. Design should be introduced in small doses throughout the junior year. In their senior year, students should be heavily exposed to design. The design experience culminates in the capstone design courses in the final year.

How does the above relate to the engineering curriculum in the French Military Academy? The fundamental courses in engineering certainly have the attributes of a normal engineering curriculum. In some cases, the names of the courses may be a bit confusing (the names are quoted from the official documentation of the Academy in English), for example *Engineering Physics* in semester 2 and 4 (see Table 1) should rather be called *Engineering Mechanics* as it combines statics, dynamics, solid mechanics and fluid mechanics. Also course *Theory of Machines* in Semester 4 is actually a course equivalent to *Thermodynamics II* in an ordinary engineering degree programme. Irrespective of the nomenclature and the names of the courses, the fundamentals of engineering science are covered in the programme offered. However, what is really missing from the programme is the students' exposure to design. As the programme is rather short, there is simply no time to allow for design experience. The substitute for this is the engineering project carried out during the work-placement abroad.

EXAMPLE OF A PROJECT

A project with the final title *Analysis and Synthesis of Mechanisms for Awning Windows Linkages* was undertaken by a student from the French Military Academy at the Department of Mechanical Engineering, University of Botswana, from September to December 2006 [2]. The aim of this project was to find the best mechanisms that satisfy the production requirement of awning windows (horizontally opening windows) in Botswana. In order to determine the type and dimension of these mechanisms, different linkages were studied using analysis and synthesis by mathematical and graphical methods, and by the application of two professional software: *Robert's Animator* and *Watt Mechanism Design Tool* (both by Heron Technologies). The linkages for awning windows were compared using three criteria: the existence of toggle positions, the value of the transmission angle and the mechanical advantage. These criteria made it possible to classify the linkage from the mechanical point of view. The costs of production were also considered and finally chosen as the critical criterion in the selection of the mechanism.

Project Statement

The main system of windows used in Botswana is the vertical opening mechanism. This type of window is not the most suitable for Botswana because of the climatic conditions. The normal rainfall in Botswana is a short and very strong storm with a high rainfall in a short period of time. It is also normally accompanied by strong winds. In such conditions, vertical windows allow for rain water to enter inside and they have to support heavy loads due to winds. They also do not allow for the proper use of blinds. A much better solution in such conditions would be an awning window system because it is a horizontally opening mechanism. Currently, such windows are not available on the Botswana market, although they are the most popular type of windows in North America (over 5 million are sold annually in the USA and Canada). The aim of the project was to find an opening linkage that would have good mechanical properties and be easy and cheap to manufacture.

Awning Window

Awning windows are windows with a horizontal opening system where the window stays completely outside while it is opened. Usually, the window is composed of two linkages (one on the left and another on the right) and a lifting system to help the operator. When this type of window is used on a vertical wall, the main advantage is the protection of the room against bad weather and dust. Secondly, when these windows are used on roofs, the advantage is the simplicity of opening and closing. An example of an awning window is shown in Figure 1.

Figure 1: An awning window.

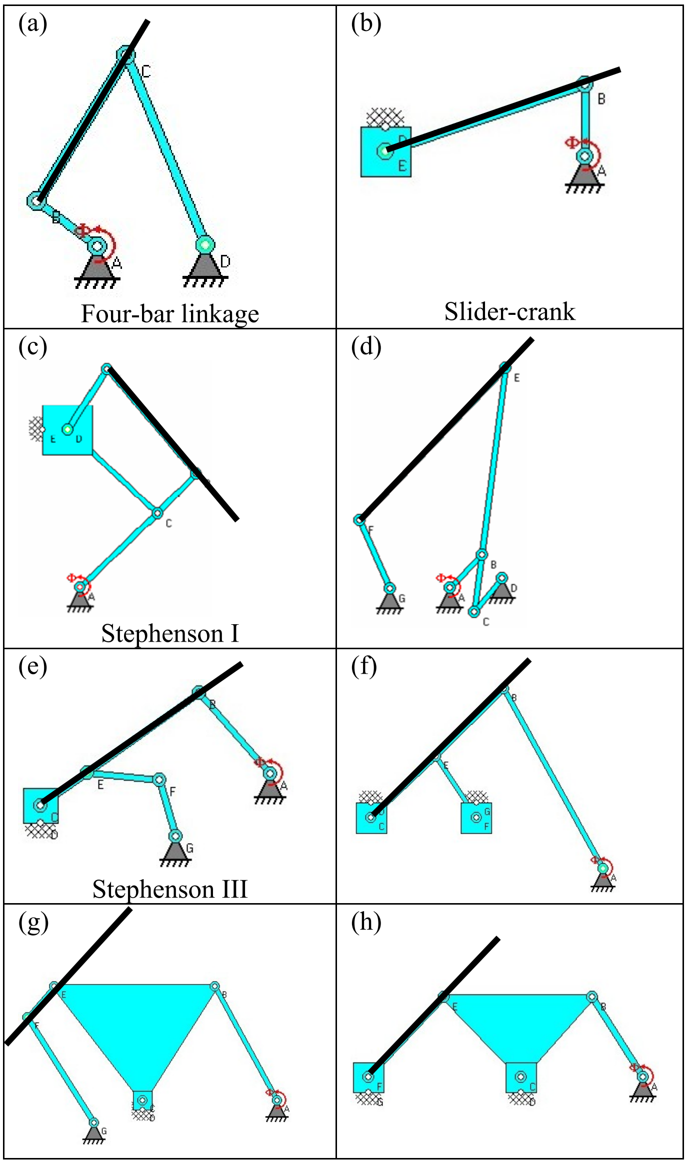
Design Constraints

For the purpose of the project, the only constraints considered were those concerning the linkages as follows:

- The window must open more than 45° from the sill;
- The end of the sash must slide in order to allow for washing on both sides of the window from the inside;
- The linkages must have one degree of freedom;
- The transmission angle of a new hinge must be between 40° and 140°.

Linkages must be as simple as possible due to economic considerations (pin and slider joints are preferred over gear and cam connections). Originally, there were eight linkages considered for the window mechanism. They are presented in Table 2 (the black solid lines indicate the position of the window sash). All had one degree of freedom with either four or six links. Based on the preliminary analysis, the last four mechanisms were discarded mainly because they would be difficult to manufacture. The remaining four linkages were designed in order to satisfy the window requirements. For simpler mechanisms (four-bar and slider-crank), the *MATLAB* procedure for the motion generation was developed based on an analytical method [3][4]. For the more complicated linkages (Stephenson I and Stephenson III), the synthesis was achieved using *Watt* software [5].

Table 2: Possible solutions for the window mechanism.



Synthesis Results

The designed linkages were compared in terms of their transmission angles, mechanical advantage, the existence of the toggle point and the force index.

The example of the results for transmission angle is presented in Figure 2 and the mechanical advantage in Table 3. The analysis of the mechanism was carried out using *Robert's Animator* [5].

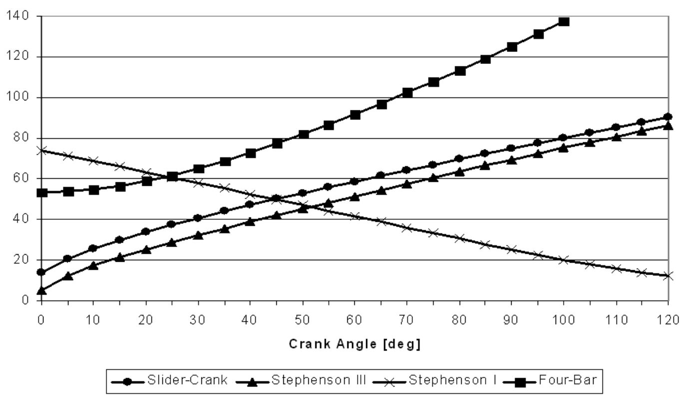


Figure 2: Transmission angle of the selected mechanisms.

Table 3: Mechanical advantage of the selected mechanism.

Crank Angle	Mechanical Advantage			
	Slider-Crank	Four-Bar	Stephenson III	Stephenson I
5°	7.16	1.82	2.68	1.68
20°	1.68	1.19	1.68	0.94
40°	0.84	0.34	1.25	0.95
60°	0.87	0.33	1.09	
90°		1.25	1	

From the mechanical point of view, the best mechanism is the Stephenson III; it has no toggle position, and the value of the transmission angle is always between 50° and 115°, which is the best range of the four mechanisms [6][7]. Finally, the value of the transmission angle in the mechanism is between 1.61 and 3.79, which shows that for a given input force, the output force is always greater. The second mechanism is the Stephenson I. Its advantage is a useful toggle position when the window is closed. The range of the transmission angle and the mechanical advantage are less suitable. The third mechanism is the slider crank. This mechanism has a useful toggle position that will lock the window. The values of the mechanical advantage is just less than the Stephenson I when the window is open at an angle of more than 40°. The least suitable is the four-bar linkage because of the very low values of mechanical advantage.

However, as the aim of the project was to find the best design for an awning window for production in Botswana, a compromise between mechanical performance, simplicity and cost of production had to be found. Therefore, the Stephenson I and III were discarded as not suitable for production in Botswana as they are more complicated in terms of manufacturing compared to the simple four-bar or slider-crank mechanism. Of the remaining two simple mechanisms, a slider-crank has been selected as the better of the two from the point of view of its mechanical properties. Also, since the slider could move along the sill, it would, therefore, support the weight of the window [8]. However, there are some restrictions on the use of this mechanism for awning windows; firstly there would still be a torque required on the sash to close it from a 90° position. Also the crank (link AB) could not be used effectively as an input link since the transmission angle is 0° in the open position. The slider (link BE) would also not be suitable as an input link since the transmission angle is 0° in the closed position. Therefore, the only solution would be to use the sash as the input link.

Stress Analysis

The stress analysis for the slider-crank linkages used as a window mechanism was carried out using the finite elements method. The software used was *RDM 6*, which gave the value of the Von Mises stress in the sections of each link. Three different types of materials were used in the stress analysis: copper, steel 335 and AU4G aluminium.

Figure 3 shows window in the 60° opened position; it is considered that the window and the links do not move. The size of the element for the window frame was assumed to be 10 mm x 10 mm (element A1B1). It shows also the stress distribution in the frame and in element A1B1 for steel 335. The analysis proved that both aluminium alloy AU4G and steel 335 can be used for the window mechanism as the maximum stresses in both cases were lower than the elastic limit of both materials.

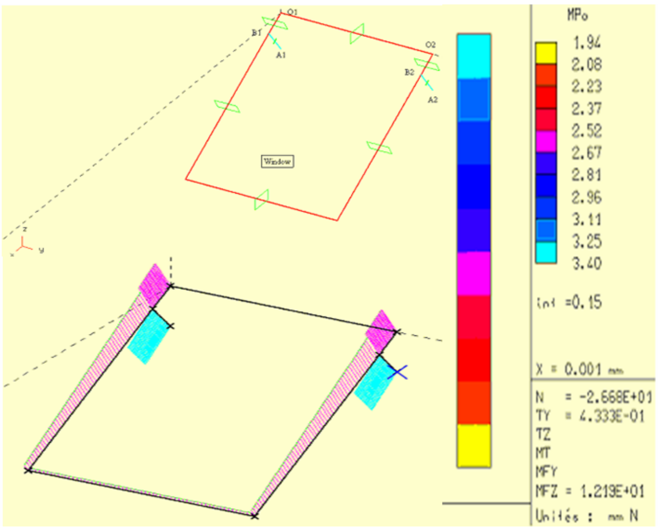


Figure 3: Stress analysis in the window.

Due to the climatic conditions in Botswana with high temperatures in summer and high humidity during the rain season, the aluminium alloy would be the ideal material for the window frames. The only factor that could lead one to choose steel rather than AU4G is the manufacturing cost, as steel is five times cheaper than aluminium.

Project Findings

Five linkages were originally compared using three criteria in order to establish which one would be the best design for an awning window from a mechanical point of view. The criteria for comparison were toggle positions, transmission angle and mechanical advantage.

Based on these three criteria, the mechanisms under consideration were classified in order to find the best of them. After considering the costs of production, the best mechanism from the mechanical point of view was not selected because of its complexity to manufacture. Instead, two less efficient but easy to manufacture mechanisms were chosen. Then, the calculation of the transmission of the external force applied to the window was carried out so as to determine the quality of these mechanisms. Finally, a stress analysis was conducted using the finite element method to determine the required strengths of the elements.

CONCLUSIONS

Project-Based Learning (PBL) is to be an efficient method to acquire new knowledge. It requires students to utilise all of their skills in order to answer driving questions. They must research, collect data, interview and adapt information in order to present a possible solution to the presented problem. It helps students to gain a proper understanding and remember new information as students tend to remember things that they have experienced or had to research on their own, because it feels like it is their own question, not just one presented during class [9].

The following are primary features of PBL:

- It is student-centred in that the topic of the project is an authentic assignment from the discipline, which would be relevant and meaningful to students' interests;
- Teaching through skills: students learn the content as they try to address a project;
- It is process-centred (more than product-centred) as the ultimate goal of learning is not about finding the best answer to a question but rather to train students to learn through the process of problem solving, ie thinking steps, research topics, development plans, etc;
- It is group-based in that the majority of the learning process takes place in groups or teams;
- It is experiential as students experience what it is like to think as a practitioner of a particular discipline.

Without doubt, all the projects undertaken by students at the French Military Academy in semester 5 during their international placement fulfil all but one of the features of PBL. The only feature of PBL not fully satisfied in the project was the fact that it was not group-based. However, even that feature had been addressed to some extent, mainly because of the specifics of the international placement. Since students are placed in different institutions in different countries, there are normally only a few of them allocated to the particular organisation, thereby creating a natural group of students who normally discuss projects between themselves. The other features of PBL are addressed through the realisation of the project. In the particular case of the awning window design, the student was allocated a practical and authentic assignment in an area of mechanical engineering that he was not very familiar with. Through that context, he had to study and learn analysis and synthesis of planar linkages, use that knowledge to design a mechanism for particular needs, and analyse it in terms of positions, kinematics and also kinetostatics. The above was achieved using graphical and analytical methods and also with the help of software that the student had to learn. He also learnt how to perform a stress analysis using the particular finite element software.

The goal of the project was always to train the student in certain aspects of mechanical engineering and not to find the best overall design for the mechanism. The latter was a secondary goal to fulfil the student's own satisfaction.

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10th Baltic Region Seminar on Engineering Education: Seminar Proceedings

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The successful *10th Baltic Region Seminar on Engineering Education* was conducted at the University of Szczecin, Szczecin, Poland, between 4 and 6 September 2006. The Seminar attracted participants from 18 countries worldwide. Just under 40 papers have been published in this Volume of Proceedings, which include an informative Opening Address about the UICEE European Headquarters and its involvement with European engineering education, plus various Lead Papers. All of these published papers present a diverse scope of important issues that currently affect on engineering and technology education at the national, regional and international levels.

The paramount objective of this Seminar was to bring together educators from the Baltic region to continue dialogue about common problems in engineering and technology education under the umbrella of the UICEE. To consider and debate the impact of globalisation on engineering and technology education within the context of the recent economic changes in the Baltic region, as well as the increasing importance placed on fostering students' entrepreneurship skills, were also important objectives of this Seminar. Moreover, the other important objectives were to discuss the need for innovation in engineering and technology education, and to establish new links and foster existing contacts, collaboration and friendships already generated in the region through the leadership of the UICEE.

The papers incorporated in these Proceedings reflect on the international debate regarding the processes and structure of current engineering education. They are grouped under the following broad topics:

- Opening address
- New trends and approaches to engineering education
- Specific engineering education programmes
- Simulation, multimedia and the Internet in engineering education
- Education and training for engineering entrepreneurship
- Innovation and alternatives in engineering education
- New developments and technologies in engineering education
- Quality issues and improvements in engineering education

It should be noted that all of the papers published in this volume were subject to an international formal peer review process, as is the case with all UICEE publications. As such, it is hoped that these Proceedings will contribute to the international debate in engineering education and will become a source of information and reference on research and development in engineering education.