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Experiences with Capstone Projects in a Master of Engineering Management Program: A case study

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Abstract:
Capstone projects in a Master of Engineering Management program are unique and there are limited publications on this subject. This paper reviews the literature on capstone projects in general, to draw lessons that can be learned to formulate the basis for designing the course. It then describes how the course objectives, teaching and learning activities and assessments are devised. A typical delivery of the course is then described where the three elements have been detailed. The main learning activities were reviews of lessons from other courses in the MEM, chosen case studies and their analyses and presentations and engagement in a team project. Out of these the first two were assessed on a formative basis. The team project and submitted case analysis were assessed on a summative basis. A table showing sample projects is presented. Feedback obtained from a sample of the two past student cohorts indicates the effectiveness of the method.

1 Introduction

Capstones are integrative learning experiences near the end of a curriculum that enhance student learning through reflection, application, and synthesis of previously gained knowledge and skills throughout the program [1]. These gained knowledge and skills allow the students to make valuable connections between theory they have learnt and the practice, and lead them into post-academia endeavors. Capstones differ from regular courses since they are integrative. With respect to the Master of Engineering Management program, the capstone course is a one-semester "putting it all together" course that gives students an opportunity to use their knowledge and skills, collaborate with their peers, practice their presentation and organizational skills and ultimately, showcase what they have learned and achieved during their residency in the Master Program. Peterson and Humble [2] studied the total undergraduate and master student intake for Engineering Management programs in USA during the year 2004. They identified that 75% of the students were taken for master programs. There are a variety of topics that are being taught in Engineering Management programs and it is not possible to include all of them in a Master's program. Inclusion of one topic means exclusion of another. Cherbaka and Lavelle [3] identified 38 topics covered as the core curriculum in Engineering Management programs and concluded that the percentage of programs covering them varies from 2 to 96. Because of the fact that Engineering Management is mainly a postgraduate program and the coverage of topics has a large variation, there is no unified capstone framework and the number of publications on Capstone projects in Engineering Management is limited. This paper describes the formulation and conducting a Capstone Project course in the Master of Engineering Management program at UAE University.

1.1 Engineering Management Program at UAE University

The College of Engineering and the College of Business and Economics at the UAE university jointly launched the Master of Engineering Management (MEM) program

initially with sixteen 2-credit hour courses in 2006. This program is the synergic integration of engineering and business skill sets that equip students with the technical expertise, leadership and the insight needed to excel through the many facets of the fast-paced world of technology. In general, a Master of Engineering Management program enhances knowledge building in engineering process and project management, quality engineering and operations research, and combines it with leadership, financial and management accounting, decision techniques and supply chain management from the business side. This equips the graduate with the knowledge and skills necessary to lead engineering teams and complex projects to achieve company desired goals. In this program, Product Development and Engineering at large is enhanced by engineering process, project and quality management and complemented by leadership skills, decision techniques, supply chain management, and financial and management accounting techniques.

At the beginning of the program sixteen 2-credit hour courses allowed the coverage of a wide variety of topics, which were meant to address the needs of the industry at large. However, after five years the colleges decided to streamline the program while maintaining the program's competitiveness and value to the students and community at large. Some courses were merged and new courses were born. The sixteen 2-credit hour courses were reduced to eleven 3-credit hour courses. One of the new-born courses was the Capstone. This paper describes the development of the 3-credit Action Project (Capstone) course and the experiences gained in the design and delivery of it.

2 Literature Review and the Formation of the Basis

2.1 Contents for Capstone Project

Capstone design experience for senior undergraduate students has been a topic of interest for more than two decades. Martin et al. [4] states that there must be sufficient course work in the appropriate engineering science upon which the capstone design experience would be built. They also state that capstone project expose the students to a problem where the answer, and usually the techniques leading to an answer, are not readily apparent. Additionally, the capstone experience requires students to combine engineering skills with other essential abilities, such as communicating effectively both orally and in writing. Early capstone courses followed a case study-based model where the focus is on a contemporary case study [1]. In many instances the capstone courses now, focus on experiential or problem based learning. Duston et al. [5] reports an earlier classification of experiential learning activities in 1976 into two areas namely (i) those that have "simulations" and (ii) those that have "authentic involvement." Simulations consist of contrived situations that are carefully designed to meet selected learning objectives and are under close faculty control. The authentic involvement activities expose the student to real situations with totally open-ended projects, although the faculty may influence the selection of the situations and set performance criteria to assure that positive learning objectives are met. Authentic involvements use outside clients while simulations use experimental laboratories, guided design, or case studies. In an article in 2006, Davis et al. [6] defines "*the purpose of the capstone engineering design course is to provide students authentic engineering design experiences:*

i. *in which teams develop design products to meet specific needs while complying with technical, business, professional, and societal constraints, and*

ii. *by which students' design performance can be assessed with validity*".

2.2 Characteristics of Good Capstone Project

Bachnak et al. [7] list the characteristics of a good capstone project as (i) solvable in 200-400 man hours (ii) requires research and design (iii) requires a team of 2-3 students (iv) be a back-burner type of project rather than involved with main stream production. Mckenzie et al. [8] from a national survey suggest that there is a need for comprehensive projects. Duston et al. [5] summarize the features of a good project as (i) be challenging (ii) have good chances for successful completion (iii) be common enough so that there is literature available (iv) emphasize the applicability of theory (v) involve engineering design work (vi) meet specific standards and safety criteria and (vii) not involve proprietary information if industry is involved. They also state that the instructor can limit the scope of the project to a level that is appropriate for the duration of the course.

2.3 Learning Outcomes from Capstone Courses

Pierrakos et al. [9] describe a survey to identify the top student learning outcomes. They considered twenty personal and professional outcomes and thirty technical learning outcomes in their survey. Among many other findings they found that the three highest ranked student outcomes are "personal and professional learning outcomes," (i) pertaining to working in teams where knowledge and ideas from many engineering disciplines must be applied (ii) communicating effectively and (iii) valuing that students taught and learned from each other. The three highest ranked "technical learning outcomes" include (i) being able to generate multiple design concept alternatives, (ii) recognizing the need to consult an expert and (iii) applying basic scientific and engineering principles to analyze the performance of processes and systems.

2.4 Assessment of Capstone Projects

Laguette [10] argues that a capstone project should be assessed for (i) problem scoping (ii) concept generation and (iii) solution realization and points out that there is a noted absence regarding the expectations and assessments in regards to the final outcome of the design project, solution of the defined problems (or Solution Assets). Davis et al. [6] assert that four areas of performance characterize design: (i) personal capacity (ii) team processes (iii) solution requirements and (iv) solution assets and argue that examining achievements in these four performance areas becomes the focus for assessment in capstone engineering design courses. They present the following as the basis for assessment of each area as follow

i. Personal Capacity: Individuals accomplish challenging goals related to design by employing goal-driven initiative, competence in problem solving, integrity and professionalism, and ongoing reflective development of their personal abilities.
ii. Team Process: the team achieves challenging goals in productivity and team function by strategic use of team resources, synergistic collaboration, added value decisions, and assessment-driven refinement of processes.
iii. Solution Requirements: Specifications reflect in-depth understanding of customer wants and needs, business issues, state of the technology, and societal concerns about the solution, and provide clear targets for development of a valuable solution.
iv. Solution Assets: Design solutions meet or exceed expectations of stakeholders

by delivering proven value in desired functionality, economic benefits, implementation feasibility, and favorable impacts on society.

2.5 Teaching Capstone Courses

The key fundamental features of engineering design can be identified as a need, safety, performance, manufacture-ability and a full set of engineering documents. This can be argued that capstone design project should at least satisfy these key fundamental features [12]. For mechanical capstone projects, they advocate a virtual factory-based approach where each student and design team can design, construct virtual components, virtual assemblies and the virtual product, and numerically test virtual components and virtual assemblies. It follows that capstone courses in engineering management also should have a set of key features and every capstone project should satisfy these key features.

2.6 Course or Curriculum Development

At the planning level of a program, the university in collaboration with the constituencies, establishes the addition to the student's skill set, as a result of following the program. These are called student outcomes. Course Outcomes on the other hand are expressions describing the desired abilities, in comprehension, application and integration, the student achieve during a course that is part of the program. These are defined and derived to achieve the student outcomes of the program. Design of a course at the delivery level involves the establishment of three constituents namely (i) course objectives (ii) definitions of instructional activities and material and (iii) assessment strategies.

The course objectives are specific, concise and measurable representations which when achieved the intended course outcomes are also met. The instruction materials are developed to achieve these objectives and by achieving these objectives the course outcomes are met. In learner centred teaching, teachers articulate what they expect the students to learn, design educational experiences to advance their learning, and provide opportunities for them to demonstrate their success in achieving those expectations [13]. Whetton [14] states that, most important professing of a professor involves his thoughtful choice of reading materials, assignments, activities and most of all learning objectives. This is even more pronounced when the instructor has to choose a project from a wide variety of engineering applications.

Assessment of the course is the process of gathering and discussing information from multiple and diverse sources in order to understand what students know, understand, and can do, with their knowledge as a result of their educational experiences. Carnegie Mellon University [15] states that '(i) Where do we want students to be at the end of a course or a program? and (ii) how will we know if they get there?' are the two questions at the heart of assessment. Assessments are classified into (i) formative assessment, which aims to *monitor student learning* to provide on-going feedback to students to improve their learning and to teachers to improve teaching and (ii) summative assessment, which aims to evaluate student learning at the end of an instructional unit.

Alignment is the focussing of the objectives, instructional activities and materials and the assessments for the common goal of enhancing learning. As Andersan [16] puts it "Curriculum requires a strong link between (i) objectives and assessments, (ii)

objectives and instructional activities and materials and (iii) assessments and instructional activities and materials. In other words content validity, content coverage and opportunity to learn are included within the more general concept of Curriculum Alignment".

2.7 Cognitive Process

Bloom's original taxonomy divides the cognitive process into six categories knowledge, comprehension, application, analysis, synthesis and evaluation arranged in that order. It is a framework for classifying statements of intentions or expectations on what students should learn (educational objectives) as a result of instruction. Krathwohl [17] provides Revised Bloom's Taxonomy by renaming some of them and changing the order. The new order starts at Remember and goes through Understand, Apply, Analyse, Evaluate and Create in that order. Each one of them has sub-categories. They can be represented in a schematic diagram as the one shown in Figure 1. It is worth noting that the objective statements at a capstone course should be at the later stages of the cognitive process.

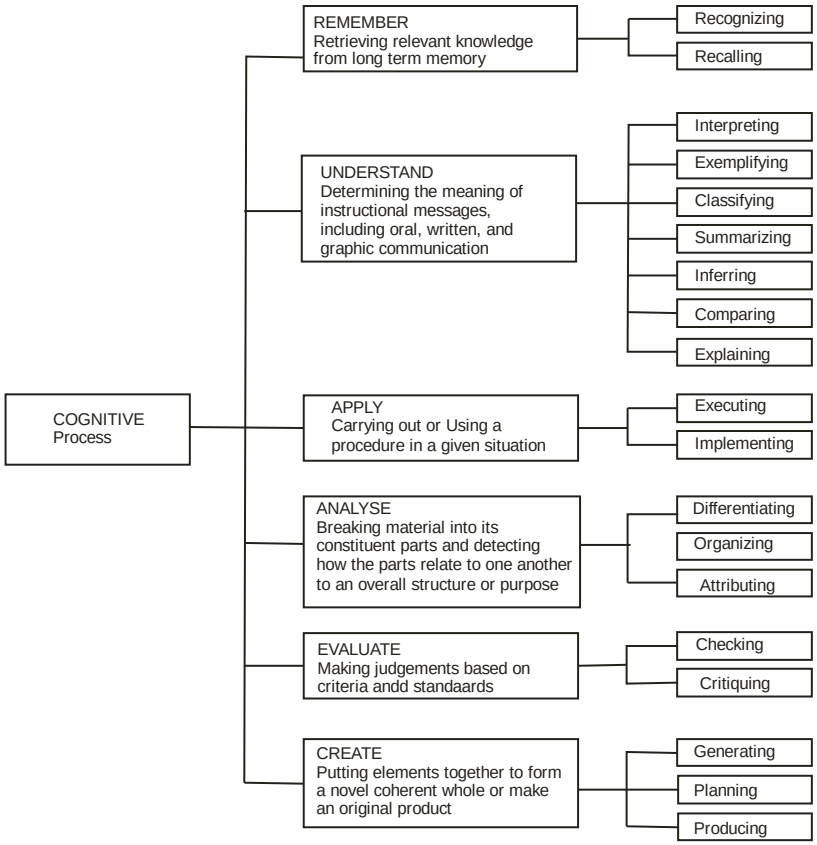

Figure 1: Revised Bloom's Taxonomy

With these observations in mind the course objectives, instructional activities and materials and the assessments were defined. Section 3 describes them.

3. Development of the Curriculum for Action Project (Capstone).

The course was developed considering the lessons from the literature. Table 1 shows the development.

Table 1: Course Development Based on Findings from Literature

Elements	Findings from Literature	Proposed Course Elements
Objective	Enhancing Integrative learning of previously gained knowledge and skills through reflection, application, and synthesis	Enhance integrative learning of previously gained knowledge at the advanced stages of Bloom's taxonomy (Analyse, Evaluate and Create)
Contents	The project should have no obvious answer and should cover a wide area taught in other courses.	Problem/project based learning through carefully designed simulation projects having relevance to the country and local people and permitting evaluation of student's ability. Authentic touch is given through the carefully chosen case studies. Alternately this can be given through industrial visits, which is resource-intensive.
	Early Capstones were mainly Case Study analyses but now they are Problem/project based learning exercises.	
	The projects can be authentic and simulations	
	Projects should have specific needs and constraints of various kinds.	
	Project should lend itself to evaluate student's ability.	
Characteristics of good projects	(i) solvable in 200-400 man hours (ii) requires research and design (iii) requires a team of 2-3 students	The project should avoid mundane time consuming tasks and engage the students in tasks that enhance the learning process. Providing appropriate output data by the instructor may cut down tasks and ensure that each student contributes an average of 100 – 125 hours of work.
	Should be a back-burner type of project rather than involved with main stream production	
	Should be challenging but have good chances for successful completion	
	Should be common enough so that there is literature available and emphasize the applicability of theory	
	The instructor can limit the scope of the project	

Table 1: Course Development Based on Findings from Literature contd.

Elements	Findings from Literature	Proposed Course Elements
Learning Outcomes of the course	Outcomes are categorized into personal and professional outcomes and Technical outcomes.	At the end of the course the students will be able to 1. Work in multi-disciplinary teams 2. Communicate effectively in both oral and written format. 3. Analyse and identify the required skill set and the available skill set. 4. Apply Engineering and Management principles and practices (tools) to solve problems innovatively. 5. Generate alternative engineering and managerial solutions and systematically evaluate them. 6. Analyse others experience and case studies and evaluate them.
	Pertaining to working in teams where knowledge and ideas from many engineering disciplines must be applied	
	Communicating effectively and teaching and learning from each other.	
	Recognize the need to consult experts.	
	Ability to apply scientific principles	
	Generate alternative solutions and systematically evaluate them.	
Assessment in two areas (Personal & Product)	Personal Development - Personal capacity and team processes	Learning Experience emphasize Group work or focusing on self, team work and management focusing on team, and learning and teaching one another (first three outcomes) Solution Route and the End product (last three outcomes)
	Solution Development - Solution requirements and solution assets	
Curriculum Development	Establishment of three constituents namely (i) course objectives (ii) definitions of instructional activities and material and (iii) assessment strategies.	Discussed in section 3.2.
	The three components should be aligned	
Cognitive process	The learning process is divided into six stages Remember, Understand, Apply, Analyse, Evaluate and Create in that order.	The task should be challenging enough to work in the analyse, evaluate and create stages.

3.2 Curriculum Design

Curriculum design is the establishment of the three constituents namely (i) course objectives (ii) definitions of instructional activities and material and (iii) assessment strategies. Course outcomes express the changes that the student will achieve by going through this course. The course objectives formulated by the instructor, define the tasks that the student will carry out to achieve these changes. It may include the scoping of the project through literature survey, establishment of the project charter, planning the project, customer interview and so on. It may also include learning a specific number of case studies. The next constituent is the definition of instructional activities and material. The activities centre on the 'analyse, evaluate and create' stages of the cognitive process. As the objectives in Table 1 suggest the first part focuses on developing personal outcomes on teamwork, skill assessment and effective communication. The second part focuses on the development of the product/project. With the time limitation and objective of gaining the most out of the class theory, the students are engaged with case studies. Best case studies practices are the ones from Harvard [18 - 20]. The cases are selected very carefully among thousands of available cases. The expected elements from these cases are the company analysis and its background, evaluation of the company performance and creation of a decision on why this company reached this level. Students are asked to analyse and evaluate the qualitative information in the case describing contemporary real life and produce a report of only one page length. By doing this challenging one page analysis, students are prepared to be able to express their thoughts on complex issues and express their experiences in only one page.

Alignment is a fundamental requirement where the objectives are drawn to achieve the learning outcomes, the learning activities and materials are developed to meet the objectives and assessments are focussed to assess the level of attainment of the objectives. With this principle in mind the assessment of the capstone project should focus on assessing the personal development part and the project development parts in the project. Section 4 discusses the specifics of the course.

4. Typical Delivery of the Course

For easy comprehension this section is divided into the three constituent parts, course objectives, learning activities and materials and assessment.

4.1 Course Objectives

The main objective is to enhance integrative learning by using previously gained knowledge in analysis, evaluation and creation. This is achieved through the following:

1. A review of the knowledge and skills gained through other courses with special focus on concepts of project planning including use of activity network approaches and forecasting techniques.
2. Further the students are expected to use project network scheduling techniques including the use of Gantt chart and critical path method and concepts including time-cost trade off analysis, resource management including resource levelling and allocation, cost and schedule control, and forecasting, on selected practical project.
3. Analyses of at least three chosen case studies emphasizing case analysis, class discussions and group projects to develop skills in applying these concepts. It

also incorporates aspects of professional written and oral communications and group teamwork.

4. Completion of a continuously monitored hypothetical (simulation) project from concept to completion.

4.2 Learning Activities and Materials

An essential part of this course will be effective teamwork outside the class on case preparations, group presentation and the project itself; yet the instructor will refrain from assigning teams. Experience suggests that four students is an ideal group size, with three or five acceptable. However, some of the students may be happy with the groups that he/she worked with in other courses. In the case of preparing new groups, students are encouraged to seek group members from different industries and management experience backgrounds to broaden their own perspectives and share the class experience resources. The instructor distributes to the students best practices in Harvard cases analysis to study and learn from. The class of the capstone course is divided into three parts, as follow, overview of the topic that the case is covering, case discussion, and todays title in the management and business newspapers and magazines. For instance Bulongs Case Study [21] mainly talks about the financials and their inputs to make the company succeed or fail. Before the case was studied, finance and related theories were discussed in the class. The case study is then discussed and the students are asked to submit a one page case analysis on the following day. In our university experience, we chose different cases for different objectives. These are weekly case study analyses and students are individually assessed.

4.3 Assessment – Formative and Summative

Formative assessments are assessments where the students get feedback and opportunity to correct and resubmit if appropriate. They are aimed at improving their personal skills and in this course class contribution, group collaboration and team working are formatively assessed. In another supporting assessment of this kind the groups are asked to attend classes as they attend formal meetings with executives. In this respect they need to prepare for any updates that executives may require; File should be prepared for each group, showing the responsibility and progress of each task every week and any delays in any task. The 'case method' of management education as used in this course is a subject of controversy and debate among students and faculty, and merits clarification. Its objective is to develop skills in problem identification, analysis of issues and alternatives, communication of conclusions and recommendations, and generalization to other situations. This covers the first three learning outcomes in Table 1 in a well-rounded manner.

As mentioned earlier, an essential part of this course will be effective teamwork outside class which forms the summative assessment. This reflects the last three learning outcomes in Table 1. In the first week itself the students are asked to form teams and select one topic to write a report about it. Summative marks are collected from two individual case paper analyses, group project (paper and project file) and presentation, and homework and assignments. These assignments are spontaneous based on any specific case study discussed on a day and the students' responses and body languages at the case discussion. Typical examples of the projects are given in Table 2.

Table 2: Example Projects Showing Important Details

Project Title	Student Background	Aim	Brief Description	Tools Used	Innovative Idea & Motivation
Digital Retina Scanner	Two students medical background and one student IT background.	To develop fully automated retinal camera for the screening of diabetic retinopathy	Collecting historical data about targeted customers and patients	Forecasting, SWOT analysis, BCG, Cost analysis, 4Ps, Space matrix, CPI, PEST analysis	Case studies, group members, needs for quality service.
Supplying water and soap from the same tap	Two mechanical engineers, one civil engineer, one chemical engineer	Smart add to the market	Hands free water tap that can supply water and soap from the same tap	Breakeven and revenues, CPM,BCG, Buzz marketing strategy, Market growth, QFD, W5H2 technique, Design process, IFE/EFE, Positioning to win.	Personal and customers experience of not feeling comfortable using two different taps at the same time for the same purpose. Hygiene product, environmental friendly and provide users with a pleasant experience. Survey showed that 75% are willing to fund the product, 93% will use it, 69% rated the product for more than 80%.
GeoGrid provider	Two Field engineers, one IT engineer	High quality environmental and road infrastructure services	To provide a solution for soil reinforcement problems by using stiff polymer geogrid.	DICE, Market segment, Competitive analysis, Branding, BCG, SWOT, cost analysis, Financial ratios, quality management plan, IPO.	Field problems
High tech company	One analyst, one information system	Provide specialized software	The company would like to provide the customers with the existing software's like CRM but at high quality services and technical needs.	DICE, SWOT, 4Ps, SunTzu, Positioning, financial ratios, marketing mix, management.	Improving the customers retention and provide them with the help to adopt the new technological and advanced methods.

Table 3: Outcome Assessment.

Course Outcome	Group 1 Fall 2011	Group 2 Fall 2012
Work in multi-disciplinary teams	Tasks were assigned based on different majors in the group. Milestones and frequent meeting were set to discuss project process and group progress to achieve the set goals. This is useful in our work where multidisciplinary tasks are common	Great concept especially for shy people to express freely and also to work with both genders in professional environment. Also to learn how to cope with different ideas and discuss, instead of persistence on individuality for the sake of the team /organizational goal.
Communicate effectively in both oral and written format.	Several presentations were done for the class and several one page papers including a comprehensive marketing brochure were written. This is very useful where, 'by brief presentations to higher management we have to sell them our proposal'.	Again for shy people to express in front of good number of audience and learning presentation skills which is highly needed nowadays in each company for each member. The single sheet summary is a very good technique. Also we learned how to learn from others' experiences.
Analyse and identify the required skill set and the available skill set.	Studying of pervious similar projects provided key point ideas to incorporate into the final submission where research was done for new or unfamiliar point ideas. Tasks were assigned for group member based on available knowledge on the point idea. This goal helps us at work when we revise our process and redistribute our man power.	Each course needs different skills. Capstone gathers all those skills and even more to understand different strategies and resources needed to describe, justify and deliver the needed message behind the projects and case studies.
Apply engineering and management principles and practices (tools) to solve problems innovatively.	Our project was based on actual data obtained from utility company. It was selected to solve a problem faced by this utility company. We covered all aspects (finance, structure, breakeven points, forecasting, etc.) in the proposed company. This helps us when we create new processes where we had to study all aspects of the new process and business impact.	The course helped in the analysis of different case studies which are real cases that can happen to any student in their careers. Those cases have lessons learned and help in decision making and in best practice somehow by comparing what was done to overcome problems. Techniques used as SWOT analysis & Risk Management are practised in different companies. To learn those at young age is a step forward in personal career.
Generate alternative engineering and managerial solutions and systematically evaluate them.	A requirement for the project proposal was to provide plan "B" and evaluations for the company and its functions. This is very common in our work environment: Temporary solution is placed to solve a problem Permanent solution is proposed and implemented Implemented solution is evaluated and corrected	Research is largely used by engineers with everyday challenges faced. Alternatives are always there but using decision matrix helps in analysing those options and come into decision which one is more suitable than the other. This approach is very useful.
Analyse others experience and case studies and evaluate them.	Case studies we studied had a lot of useful scenarios. These help us in work.	Working in teams had the benefit to learn from others how they work with different challenges. Case studies given in the course provided are very useful and effective to analyse others experiences and to know causes for successes and failures.

5. **Evaluation**

Keeping contact with a complete cohort of students who have graduated is very difficult if not impossible. However some of them would lend themselves to be contacted and consulted. In this section two such groups of students were interviewed to identify how the learning outcomes resulting from the capstone project have influenced their work practices after graduating. Though the responses may not be statistically valid they give an indication on the effectiveness of the course and its contents.

6 Discussion and Conclusions

This paper analyzed the literature under the headings, contents of capstone courses, characteristics of good capstone projects, learning outcomes from capstone courses, assessment of capstone courses, teaching capstone courses, course curriculum development and cognitive process. The important lessons were then incorporated to develop the curriculum for the capstone course. The course aimed to develop the students and solution assets. The learning activities reviewed the important lessons from other courses and discussed carefully chosen case studies. The knowledge and skills gained are cemented through the implementation of a hypothetical project with carefully chosen aspects to simulate the experiences in a real life project. The assessments were both formative and summative.

The paper then discussed the experience in the UAE University in teaching the capstone courses and the successes in the outcomes. The paper showed that Capstone course in the UAE University and in general, does not need specific prerequisites but in reality it may need every course in the program as prerequisites. Analysis and reflection of the course showed that it has most requirements of a good capstone course such as research and design, team of 2-3 students, be a back-burner type of project rather than involved with main stream production and comprehensive projects case analysis. The later is important since the instructor can limit the scope of the projects when needed to a level that is appropriate for the duration of the course. These cases reduce a lifetime of a successful company into few hours' discussion and experience. The cases and the one page summary and presentations were some of the things that were remembered and used by students even after leaving the university, i.e. long life learning.

6.1 Conclusions

Capstone course in general does not need specific prerequisites but in reality it may need every course in the program as prerequisites.

For capstones in Engineering Management programs, reviewing the important parts of other courses, discussion, presentation and a one page summary of chosen cases, and working on a complete hypothetical project are good learning activities.

Students appreciate the one page summary and presentation of the cases as one of the key feature of the capstone course.

Working on a hypothetical project gives them the application experience.

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