

# Capstone Design Based Engineering Design and Outcomes Assessment

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**Abstract** – With global competition and international collaborations, there is an ever growing demand for system integrators and interface designers. Proper allocation of system and interface requirements during top down design phase and consideration of other factors such as manufacturability, testability, and reliability are critical to successful design and competitive products. ABET 2000 accreditation criteria requires engineering programs to demonstrate that each graduate meets at least the ‘a’ - ‘k’ outcomes specified in its Criterion 3. Programs are also required to demonstrate how students attain culminating design experience in their curriculum. This paper describes how the required capstone experience in our program assures attainment, assessment and continuous improvement of many of the ABET Criterion 3 outcomes.

*Keywords:* Engineering design, ABET Outcomes, assessment

## INTRODUCTION

Access to global human and natural resources has created excellent opportunities for systematic development of systems or products that are competitive, safe, reliable and environment friendly. A systemic (life cycle) approach to system/product development involves development of complete, consistent, and attainable requirements [Buede, 3]. These requirements, including the interface requirements, are allocated to subsystems and lower level components during preliminary (top-down) design phase. Design, development, testing, and integration during detailed (bottom-up) design phase should lead to an integrated system that exhibits the desired system attributes. This systemic approach has created a demand for system analysts, system integrators, and interface designers as is evident from higher salaries offered to computer systems engineers [Prism, 2]. This paper describes a systematic design process that is used in a two semester Capstone Design Project I, II course sequence and shows how most of the program outcomes are assessed and achieved to meet ABET 2000 Criteria 3 and 4 [ABET, 1].

## ENGINEERING DESIGN EXPERIENCE

ABET 2000 Criterion 4 defines engineering design as the process of devising a system, component or process to meet desired need. It is a decision making process (often iterative), in which the basic sciences, mathematics and engineering sciences are applied to convert resources optimally to meet these needs [ABET, 1]. Additionally, every accredited engineering program is required to satisfy ABET 2000 Criterion 3 Program Outcomes and Assessment which requires graduates of every accredited program to exhibit the following “a thru k” outcomes at the time of graduation. Our BSEE program requires four additional outcomes “l-o” that are also assessed.

- (a) an ability to apply knowledge of mathematics, science and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and society, manufacturability and sustainability
- (d) an ability to function on multi-disciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems
- (f) an understanding of professional and ethical responsibility

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- (g) an ability to communicate effectively
- (h) the broad education necessary to understand the impact of engineering solutions in a global and social context.
- (I) a recognition of the need for, and an ability to engage in life-long learning
- (j) a knowledge of contemporary issues
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

### **Capstone Design Project Experience**

Our B.S. in Electrical Engineering program introduces the student to engineering design process during the freshman year, to simple component level design in the sophomore year, to Introduction to Design in the junior year, and design of subsystems in required EE junior and senior level courses. This experience leads to a two semester sequence of one credit hour Capstone Design Project I and II courses during the senior year. In these courses, the student works with a faculty project advisor to develop an initial project proposal and a Capstone Design Project Milestone Check List of activities to be carried out during the two semesters. The student follows through a systematic engineering design process, as shown in Figure 1, leading to a formal written report and oral presentation of design. The student also submits ten issues reports related to various program outcomes during the two semester sequence. The written report and the issues reports are evaluated by faculty project advisor. The oral presentations are evaluated by faculty and industry representatives, who provide feedback for continuous improvement. The design process and the Capstone Design Project II Written Report follow the following steps:

#### **Introduction**

In this section of the written report, the student identifies and justifies the need for the proposed design through supporting references, develops a problem statement, and describes the scope of the design project.

#### **Design Requirements, Constraints, Codes and Standards, and Selection Criteria**

The need analysis is used to define and develop design requirements, design constraints and identify applicable codes and standard. The technical requirements define functional and operation requirements for materials, items and services including the procedures and criteria by which it will be determined that the requirements have been met. These requirements must be complete, measurable, design independent and achievable.

Constraint is a limitation or a restriction. It could be financial, time, space or resource limitation determined by the customer. Restrictions may be imposed by groups with authority derived from respect of the consumer or the power and authority provided by law. A standard is a document that establishes engineering and technical limitations and applications for items, materials, processes, methods, design and engineering practices [Middendorf, 6], [Dieter, 4]. The designer must also identify applicable standards and codes. Some of the applicable sources of codes and standards are listed below.

- Occupational Safety and Health Administration (OSHA) - defines mandatory workplace standards.
- Underwriters Laboratories Standard (UL), and the American Society for Testing and Materials (ASTM) - define prescriptive specifications and product standards.
- The National Fire Protection Association (NFPA) and the National Electric Code (NEC) - define requirements for electrical circuits and conductor size.
- Some of the Military Handbook and Standards (MIL-HDBK and MIL-STD) - include MIL- Reliability Prediction - HDBK-271, Environmental Effects – MIL-STD-461, MIL-ST-462, Environmental Conditions – MIL-STD-810, and System Safety – MIL-STD-882.

#### **Other Design Considerations**

Student must identify other factors such as economical, environmental, ethical, safety, manufacturability, reliability, testability, security and political, etc., that may be applicable to the design project and discuss how each one of these factors is considered in the design. A brief explanation of those factors, that are not applicable, should also be discussed in the report. A brief explanation of what should be covered in each factor is provided below:

- Aesthetical Considerations – discuss how the aesthetics (appearance, conformity with the surroundings) were considered in the design and how did they impact the design.

- Economic Considerations – discuss how the costs of various components and subsystems were considered during the design phase to make the overall system an economical design.
- Environmental Considerations – discuss what factors were considered in the design that reduced its negative impact on the environment.
- Ethical Considerations – discuss how code of ethics impacted the design.
- Health and Safety Considerations – discuss what and how health and safety requirements (OSHA, NEC, IEEE, ASTM, or other applicable codes and standards) and human factors were considered in the design.
- Manufacturability Considerations – discuss the factors considered in design that will make it easier to manufacture economically and environmentally (green manufacturing), and how considerations of just-in-time manufacturing, inventory, logistics, storage were considered.
- Reliability - discuss the desired reliability requirements and how they were considered and achieved in the design.
- Testability - discuss how testing of the system was carried out and how testing conditions were considered during the design.
- Sustainability Considerations – discuss how maintenance, repair, and upgrade of the design until retirement, considerations affected the design.
- Security – discuss how the physical and intellectual security was considered in the design and what impact this design had on physical and intellectual security of the environment.
- Societal Considerations – discuss what social factors were considered in the design.
- Political Considerations – discuss what political implications were applicable to the design and how they were considered in the design.
- Energy Considerations - discuss the energy requirements and what decisions affected the design requirements.
- Space Requirements - discuss how space requirement consideration affected the design.
- Weight Requirements – discuss what were the system weight requirements and how did they impact the design.

### **Feasible Alternatives**

Student must use engineering problems solving techniques, brainstorming and other combinations of substitution, deductive and reverse engineering techniques to develop feasible alternatives that meet all requirements and constraints. The student must also briefly describe how each alternative considered satisfies the requirements and the constraints. This discussion helps in assessing student's understanding of basic engineering and science principles, creativity and problem solving abilities.

### **Criteria for Selection**

The student must identify selection criteria for the design and consideration of other factors and prioritize them depending upon customer's aspirations.

### **Selection of Conceptual Design Alternative**

In case of multiple criteria for design selection, a decision matrix may be used to evaluate various proposed design alternatives. Student may use those identified other factors with appropriate priority or weights to select from alternative designs as shown in Table 1 [Love, 5]. The student then develops a project plan with activities and milestones that become the Project Checklist to track progress.

### **Preliminary (Top-Down) Design**

After selection of a conceptual design, the design is broken into subsystems and components in a top-down approach as shown in Figure 2. Overall system design requirements, along with necessary interface requirements, constraints, and applicable standards are allocated to subsystems and components. A decision criteria must be identified for each subsystem and component.

### **Detailed (Bottom-up) Design**

A selection process is used for the selection of an alternate design for each of the subsystems. Using an iterative cycle of synthesis, analysis, construction, testing, and evaluation, the design of each sub-system is achieved. As shown in Figure 3, the subsystems are then successively integrated, analyzed, tested and evaluated for achievement of the desired requirements. Then the complete systems is integrated and tested for performance and achievement of technical and performance requirements. This is illustrated in Figure 3.

Preliminary Pages, Formatting Requirements, Project Management Plan

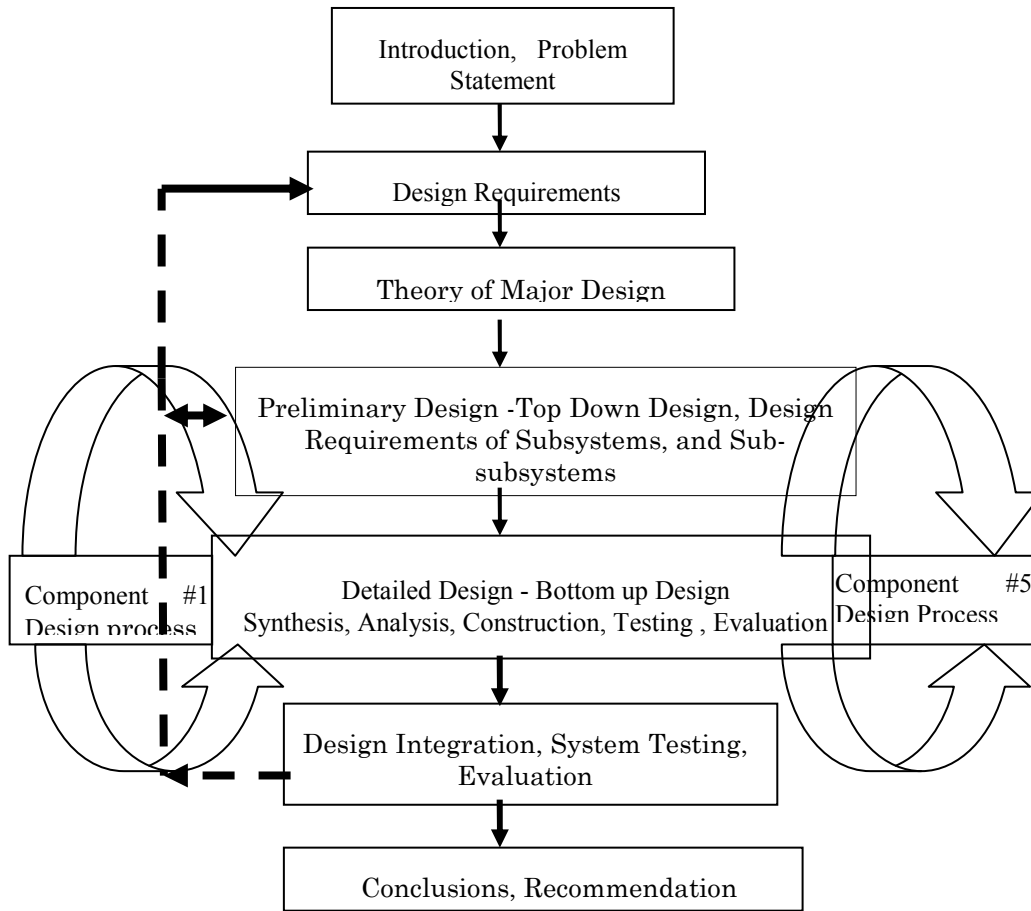


Figure 1. Capstone Design Project Written Report and Design Flow Chart

Table 1

Decision Matrix [Love, 5]

Criteria	Priority %	Alternative 1 /Total	Alternative 2	Alternative 3
Aesthetical Considerations	5	4/20	6/30	5/25
Economic Considerations	35	6/210	8/280	7/175
Environmental Considerations	15	6/90	8/120	4/60
Ethical Considerations	5	3/15	9/45	8/40
Health and Safety Considerations	10	8/80	8/80	5/50
Reliability Considerations	5	8/40	10/50	7/35
Testability Considerations	5	8/40	8/40	6/30
Sustainability Considerations	5	8/40	10/50	5/25
Security Considerations	5	8/40	10/50	6/30
Societal Considerations	5	5/25	6/30	5/25
Energy Considerations:	5	8/40	6/30	9/45
Overall score	100	640	805	540

**Conclusions and Recommendations**

The Capstone Design Project II Report must show the level of achievement of design objectives and identify principal findings. It must also show significance of the major outcomes of the design. The report may also make recommendations for further work needed in the area.

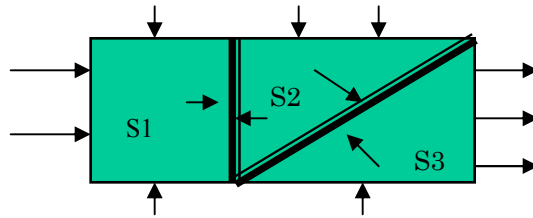


Figure 2. Breakdown of the system into subsystems and components

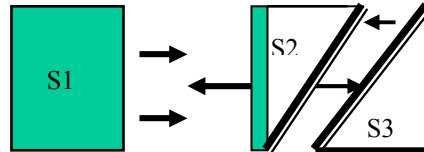


Figure 3. Design and integration of subsystems to form the whole

### ISSUES REPORTS TO ADDRESS OTHER FACTORS AND ABET CRITERION 3 OUTCOMES

A total of ten issues reports are required during the two semester sequence of Capstone Design Project courses. These reports address some of the ABET Criterion 3 outcomes as shown below. A concise word-processed summary is required for each of the issues listed below. Each report is evaluated by the faculty advisor and each grade becomes a part of each Capstone Design Project course grade.

- 1 Detailed discussion of each realistic constraint, which follow, as they are applied to the design/technical project: economic factors; safety; security; reliability; aesthetics; ethics; social factors; power requirements; size and weight; ASME, OSHA and other codes and standards (ABET Criterion 3. c).
- 2 Discussion of the design methodology, including codes and standards, used in the project (c, m).
- 3 Discussion of the mathematical, science and engineering/technical principles used in the project (a).
- 4 Discussion of the skills (programming, computational, experimental, etc.), techniques (numerical, analytical, etc), modeling/simulation (analytical, computer, graphical, numerical) and modern tools (software, computer hardware, instrumentation, etc.) required to complete the project (k).
- 5 A personal statement of being ethical and professional at all times, particularly while analyzing and/or designing a system, system component or process for your capstone project and when communicating the project ( f, g).
- 6 Discussion of the skills (programming, computational, experimental, etc.), techniques (numerical, analytical, etc), modeling/simulation (analytical, computer, graphical, numerical) and modern tools (software, computer hardware, instrumentation, etc.) required to complete the project (k).
- 7 Detailed discussion of each realistic constraint, listed below, as they are applied to the project: safety; security; reliability; aesthetics; ethics; power requirements; size and weight (c).
- 8 Discussion of how codes and standards (ASME, OSHA, etc) impact the project (m).
- 9 Provide a technical definition for quality and accuracy, and then provide detailed report on how the quality of performance and accuracy in your project is determined.
- 10 Discussion of the impact of your project in light of contemporary, social and global issues (j).
- 11 Discussion of the feasibility of implementing your project from a business and economic perspective (n).
- 12 Explain, in detail, how you plan to remain technologically current in your field over the life of your employment (i).

These Issues Reports are due at appropriate times of the design project phase. They are graded, signed, dated by the project advisor and submitted in class on or before the date indicated on the Milestones Check List. A grade must also be recorded, by the faculty advisor, on the Milestones Checklist. The class performance in various outcomes covered by the Issues Reports is shown in column IV of Table 2.

Table 2

Assessment of Capstone Design Project II Written, Oral Communication, and Issues Reports

Program Outcome	Assessment Survey	Internal Capstone Design Report*	External Oral Presentation	Issues* Reports
a. an ability to systematically apply knowledge of mathematics, science and engineering to solve problems		3.3/4.0	3.62/4.0	3.64/4.0
c. an ability to systematically identify, formulate, design and demonstrate electrical engineering systems, subsystems, components and/or processes that meet desired performance, cost time and safety requirements.		3.3/4.0	3.62/4.0	3.57/4.0
e. an ability to systematically apply knowledge of mathematics, science and engineering to the analysis of electrical engineering problems		3.3/4.0	3.62/4.0	
f. an understanding of professional and ethical responsibility				3.54/4.0
g. an ability to communicate technical information through professional quality reports, oral presentations and interaction with audience			3.47/4.0	
h. the broad education necessary to understand the impact of electrical engineering solutions in a global and societal learning			3.62/4.0	
J. Impact of design in light of contemporary and social issues				3.54/4.0
k. an ability to use modern techniques, skills and tools including computer based tools for analysis and design		3.4/4.0		3.53/4.0
m. familiarity with appropriate Codes and Standards		3.3/4.0		3.58/4.0
n. Awareness of business environment in which engineering systems are designed and developed		3.2/4.0		3.31/4.0

\* A score of 3.20 out of 4.0 is acceptable for achievement of given outcome.

**ASSESSMENT OF ABET CRITERION 3 OUTCOMES**

**Capstone Design Project II Written Report**

The final formal written reports must be prepared by following the College's guidelines for Capstone Design Project II report. This report is evaluated for written communication, use of engineering design process, creativity, application of basic and engineering science principles, analytical techniques used, level of achievement of design objectives, and report format, by the student's project advisor. A check list for review of the Capstone Design Project II report is used for conformity and is given in Appendix A. The written report is also reviewed and signed off by the department head and the College Dean.

## **Issues Reports**

The first five reports are prepared for the first part of the Capstone Design Project I course and address ABET outcomes ‘a, c, f, g, k and m’ while the next six issues reports assess outcomes “c, j, k, m and n”. The outcomes ‘m, n’ are our program outcomes. The grades of the Issues Reports are part of the over all grade for each of the two Capstone Design Project I and II courses. The student performance in all issues is tabulated in Table 3 and scores are out of 10.0.

## **Oral Presentation**

Each student must make a formal oral presentation which is evaluated by faculty, representatives from industry and alumni every semester. An oral evaluation form is used to assess the following items; (1) Introduction of oral presentation purpose and content; (2) Organization of presentation, (3) Knowledge of Technical Content, (4) Effective Conclusion of Talk, (5) Voice and Mannerism of Presentation, (6) Audio-Visual Aids used, (7) Response to Questions, and (8) Overall Evaluation of Oral presentation. This is used to assess communication skills and ABET Criterion 3 outcomes listed in column III of Table 2, which shows achievement of these outcomes based upon criteria described below.

## **Conclusion**

The average ratings of various outcomes covered by the Capstone Design Project II Written Reports, Oral presentations, and Issues Reports are shown in Table 2. The table shows successful achievement of these outcomes based upon 3.25 out of 4.00 as the acceptable rating. The quality of design projects and oral communication of our graduating seniors indicates continuous improvement. This was attested by the Industrial Cluster members who review these presentations every semester.

## **Acknowledgement**

The author would like to thank and acknowledge deep appreciation to Dr. Decatur B. Rogers, Dean, College of Engineering, Technology and Computer Science and also Professor for the Capstone Design Projects I and II, who provided the evaluation scores of all the Issues Reports over the past four semesters.

## **REFERENCES**

- [1] ABET Engineering Accreditation Commission, “2005-2006 Criteria of accrediting engineering programs.” [on line] available: <http://www.abet.org>
- [2] ASEE Prism, April 2005, pp. 17.
- [3] Buede, Dennis, The engineering design of systems - Models and Methods. John Wiley, New York: 2000. pp. 136.
- [4] Dieter, George. Engineering Design - A material and processing approach. McGraw Hill Co., New York, NY: 1983.
- [5] Love, S. F. Planning and creating successful engineered designs. Van Nostrand Reinhold Co., New York, NY: 1980.
- [6] Middendorf, William, Design of devices and systems. Mercel Dekker Inc. New York, NY. 1986. pp. 54--57.

## **APPENDIX A. CAPSTONE DESIGN PROJECT REPORT CHECK LIST**

Project Advisor should check the final Capstone Design Project II report for the following content and format before submission of final report.

### **Format**

Check border margins, consistency in spacing between chapter headings and first starting line and subheadings. All text should be double spaced in font 12 of Ariel or Times Roman. Margins for all pages should be 1.5 inch on top and left side and 1.0 inch on right and bottom sides except on the first page of a chapter and individual pages where the top margin should be 2.0 inch. Also, the page number should appear on the top right corner located 0.75 inch from top and 1.0 inch from right edge, except the page number on the first page of a chapter and individual sheets will be in the middle of the page 0.5 inch from the bottom. The headings, subheadings and sub-sub-headings must be

consistent and appropriately differentiated. Also the spacing between headings and paragraphs should be consistent. The report should be written in 3<sup>rd</sup> person.

### **Preliminaries**

- i. Cover page (check format, spellings, College Name) (must)
- ii. Signature page (check format, spacing, margins) (must)
- iii. Abstract (should be single spaced and indented text). Abstract should contain a brief description of context, purpose, and nature of the work described in the report, a brief listing of major results or accomplishments and significance of those accomplishments) (must)
- iv. Dedication (should be double spaced, one paragraph only) no long stories (optional)
- v. Acknowledgement (acknowledgement of advisory committee, and any research sponsors) (Optional)
- vi. Table of Content - use Table of Content Continued, if more than one page (check alignment of all titles and subheadings, match titles within text, check page numbers match) (must)
- vii. List of Figures (Check that titles and page numbers match exactly) (must)
- viii. List of Tables (Check that titles and page numbers match exactly) (must).
- ix. Nomenclature (Optional).

### **Chapters**

**Chapter I** – Use appropriate title or INTRODUCTION.

- A. Introduction.
- B. Need Analysis – check reference to current research work or state-of-the-art of the topic, analysis should support development of requirements and should include significant referencing or citations.
- C. Problem Definition – should define the scope of the design or the research, goal and objectives and Problem Statement
- D. Preview of Report Organization.

**Chapter II- with appropriate title or SPECIFICATIONS AND ALTERNATIVE SOLUTIONS.**

- A. Specifications – check that specific technical requirements are clearly defined.
- B. Constraints - check how other factors are addressed in the design, e.g., standards and codes, etc.
- C. Alternative Approaches – check that alternative concepts are feasible and discuss how they compare to each other based on the requirements.
- D. Selected Alternative – check selection approach from among the alternatives
- E. check for the layout of the proposed alternative in block diagram form.

**Chapter III** This chapter should be appropriately titled to show design of project or use some of following (THEORY, BACKGROUND AND PRELIMINARY DESIGN OF SELECTED APPROACH).

- A. Check for the use of top-down approach, identification of sub-subsystem or logical functional blocks
- B. Theory of major subsystems, logical blocks or models
- C. Check allocation of overall and interface requirements, codes and standards, and constraints to each subsystem component or functional block of the project
- D. Check development of feasible design alternatives for each subsystem or functional block, and selection of one design alternative for each component using appropriate criteria and consideration of other factors such as economical, ethical, aesthetics, safety, reliability, maintainability, testability, manufacturability, social, environmental and political factors.

**Chapter IV** This chapter should be appropriately titled or use some of the following (DETAILED DESIGN, DESIGN ANALYSIS, TESTING, IMPLEMENTATION, AND DESIGN VERIFICATION).

- A. Verify use of the design process namely; (1) Synthesis; (2) Analysis; (3) Construction; (4) Testing; and (5) Evaluation, repeat this cycle, if not satisfied, by going to (1)
- B. Check design of each sub-system and integration of all sub-systems to make the whole system.
- C. Check design implementation, construction and verification.
- D. Check for logical conclusions and statement on significance of conclusions.
- E. Describe the operation of overall design and how the cost constraints are being meet.
- F. Provide a demo of the final work.

**Chapter V** This chapter should be appropriately titled or use as CONCLUSION AND RECOMMENDATIONS



**References** (Check for conformity) (See samples for book and paper references) (must)

1. Ulrich, K.T., and Eppinger, S.D. Product Design and Development. Madison, WI: Irwin McGraw Hill, 2nd Edition , 2000. pp. 34-40.
2. Davis, J., "Transients in Power System." IEEE SoutheastCon'89 Proceedings, April, 1989. pp: 23-30.

**Appendix** Check for inclusion of only necessary supporting documents that are absolutely essential. They should be within margins, and readable.

**Biographical Sketch** - include one page resume

**Sample format for Tables and Figures**

Table 1.1

Fall 1997 Faculty Workloads

Faculty	Equiv. Load	SCH	Research	Advisement	Total
Proefssor-1	11.0	120	1.0	3.0	15.0
Professor-2	12.0	233	0.0	3.0	15.0

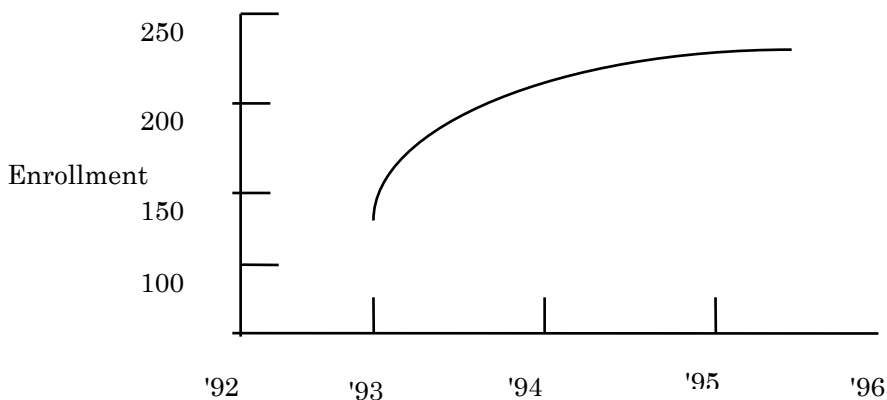


Figure 1. Student Enrollment.

Table 3

Assessment of Issues Reports (scores out of 10.0)

Sem	IR-1	IR-2	IR-3	IR-4	IR-5	R-6	IR-7	IR-8	IR-9	IR-10	IR-11
F'05	9.064	8.913	8.728	8.644	8.838						
S'06	8.76	7.868	8.773	8.67	8.137	8.44	7.95	8.03	8.09	8.79	8.17
F'06	9.68	9.0	9.44	9.29	9.38	8.89	8.54	8.28	8.49	7.84	7.59
S'07	9.34	8.969	9.504	8.596	9.054	9.15	9.15	8.63	8.48	8.22	9.09
Ave.	9.21	8.69	9.11	8.8	8.85	8.83	8.85	8.31	8.35	8.28	8.28

**Satinderpaul Singh Devgan**

Dr. Satinderpaul Singh Devgan is Professor and Head of Electrical and Computer Engineering at Tennessee State University. He received his M.S. and Ph.D. degrees in Power Systems from Illinois Institute of Technology before joining Tennessee State University in 1970. He has developed and implemented new M.S. and Ph.D. in Computer and Information Systems Engineering (**CISE**) programs, and has published in IEEE and ASEE Conference Proceedings. He is a recipient of Outstanding Researcher of the Year award in 1994 from Tennessee State University and was inducted to its Million Dollar Research Club. He has served as an IEEE ABET Evaluator and as Secretary/Treasurer, Vice-Chairman and Chairman of the ECE Division of ASEE. He is a Life Senior Member of IEEE and ASEE, a member of Eta Kappa Nu and Phi Kappa Phi Honor Societies and is a Registered Professional Engineer. He is past-chairman of Southeastern Association of Electrical Engineering Department Heads (SAEEDH) and is currently serving as Secretary of the BOD of Southeastern Center for Electrical Engineering Education (SCEEE). He also served as Editor of ECEDHA Newsletter until 2007.