Measurable Course Outcomes to support the Program Outcomes and objectives
(Last Updated: October 2008)

M**easurable course-level student learning outcomes** are defined for all program outcomes such that demonstrating that students have achieved the course outcomes provides supporting evidence that students are achieving the program outcomes and are prepared to achieve the program educational objectives.

The objectives (shown as underlined headings) flow down to the program outcomes (shown in bold, with identifying letters corresponding to the ABET criterion 3 outcomes) then to the measurable course outcomes in the tables. For each measurable course outcome we define a a tollgate course (where the final assessment takes place), a performance level (see attachment 1a), and an area of expertise group. The tollgate course is not the only place in the curriculum that the outcome is addressed, but is the one place in the curriculum that it is most appropriate for assessment of student performance relative to that outcome. The area of expertise group provides oversight and broad perspective in the review of the assessment evidence to ensure that assessment is a program-level activity rather than an individual instructor activity.

> **Area of Expertise Group 1: Thermal Systems, Lab / Experimental Methods, and Service Courses** [Members as of September 2008: Jun Choi, Izzi Urieli, Dave Bayless, Carole Womeldorf, Khairul Alam, Jesus Pagan]
>
> **Area of Expertise Group 2: Mechanical Systems, Materials & Manufacturing, Design, and Computers/Simulation** [Members as of September 2008: Bob Williams, Rudy Pasic, Frank Kraft, Jay Gunasekera, Greg Kremer, Ken Halliday, John Cotton]

A **program indicator [PI]** designation is used to identify course-level outcomes that serve as good indicators of performance for each program level outcome. These representative outcomes are checked every year to maintain continuity of assessment, while all other outcomes are formally assessed at least once every 3 years. More frequent assessments occur if course or curriculum changes warrant a reassessment.

Outcomes that support objective 2: Graduate mechanical engineers with technical skills

[ABET-b] OU ME graduates will demonstrate an ability to design and conduct experiments, as well as to analyze and interpret data.

Measurable Outcome Statements supporting ABET-b: experiments outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
b.1) An ability to perform statistical data analysis of univariate and bivariate data sets	ME288	Mastery	1
b.2) An ability to perform curve-fitting of multivariate data sets	ME388	Mastery	1
b.3) An ability to calculate the error/uncertainty propagation for calculations that include multiple terms with uncertainties	ME388	Mastery	1
b.4) An ability to design and plan experiments using real-world hardware **[PI]**	ME488	Competence	1
b.5) An ability to use common measurement equipment	ME388	Competence	1
b.6) An ability to describe basic *Design of Experiments* techniques	ME288	Awareness	1
b.7) An ability to apply previously-learned engineering concepts to compare theoretical predictions with actual experimental results in diverse, practical mechanical engineering experiments.	ME388	Competence	1

[ABET-c] OU ME graduates will demonstrate an ability to 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 safety, manufacturability, and sustainability.

Measurable Outcome Statements supporting ABET-c: design outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
c.1) Problem solving skills, including the ability to convert an open-ended problem statement into a statement of work and/or a set of design specifications	ME470	Competence	2
c.2) The ability to generate creative and feasible alternative solutions to open-ended design problems, using precedent, lessons learned, and methods such as brainstorming or functional block diagrams [PI]	ME470	Competence	2
c.3) The ability to use common methods such as decision matrices for comparing alternatives and making engineering decisions	ME470	Competence	2
c.4) The ability to apply engineering analysis (including load and stress analysis) for the design/sizing of mechanical components based on likely failure modes and meaningful factors of safety	ME303	Mastery	2
c.5) The ability to select machine elements (such as bearings, gears, or fasteners) to satisfy specific functional requirements	ME471	Competence	2
c.6) The ability to apply useful tools for design refinement such as value engineering, design for manufacturing and assembly (DFMA), or similar tools	ME471	Competence	2
c.7) A recognition of various methods for managing risk and quantifying and improving system reliability, and an ability to apply failure modes and effects analysis (FMEA) in a design project	ME471	Competence	2
c.8) An ability to deal with engineering standards and most of the following constraints in engineering design: economic, health and safety, environmental, ethical, social, political, manufacturability, sustainability. [**PI**]	ME470/1/2	Competence	2
c.9) The ability to apply general project management tools such as Gantt charts, Pareto charts, and critical path analysis for planning, prioritizing, and scheduling tasks in a design project	ME470/1/2	Competence	2
c.10) The ability to use basic manufacturing skills (such as machining, grinding and turning) and the ability to work with vendors / part suppliers to build and assemble prototypes of a product design	ME471/472	Competence	2
c.11) The ability to evaluate and use test results for design improvement and validation	ME471/2	Competence	2
c.12) The ability to design, implement and evaluate controllers for linear systems	ME401	Competence	2
c.13) The application of heat transfer to thermal design	ME412	Awareness	1

[ABET-e] OU ME graduates will demonstrate an ability to identify, formulate, and solve engineering problems

Measurable Outcome Statements supporting ABET-e: problem solving outcome, OU ME graduates will demonstrate	Tollgate Course	Performance level	Area of Expertise Group
e.1) A working knowledge of estimation techniques, rules of thumb, and engineering heuristics	ME471	Awareness	2
e.2) An ability to appropriately interpret calculated results in the context of uncertainty (in the data, the models, the assumptions, or the analytical methods)	ME303	Competence	2
e.3) An ability to solve common engineering problems, including problems involving			
a. Linear system modeling and analysis of 1 DOF system responses due to free and forced input	ME491	Mastery	2
b. The ability to model and simulate single-input single-output linear systems	ME401	Mastery	2
c. Application of the first law of thermodynamics to the analysis of energy components and systems including at least one of the following [**PI**] 1. Ideal Stirling and air standard power cycles 2. Steam power plant components and systems 3. Refrigeration and heat pump components and systems	ME321	Mastery	1
d. The application of the first law of thermodynamics to the design process	ME328	Competence	1
e. The selection of materials for mechanical components based on design considerations	ME304	Competence	2
f. The selection of materials for mechanical components based on manufacturing issues	ME471	Competence	2
g. The application of numerical techniques (of differentiation and integration) for simulating the behavior of engineering systems	ME401	Mastery	2
h. The application of statistical analysis to manufacturing, including the computation of process capability and the understanding of statistical process control	ME314	Competence	2
i. Kinematic/Dynamic analysis skills, including: 1) Analysis of position, velocity and acceleration kinematics of mechanisms 2) Analysis of inverse dynamics of mechanisms 3) Basic analysis of cams and gears*	ME301	Competence * awareness for i3	2
j. The application of the fundamentals of fluid dynamics to the design process	Prerequisite Inventory in ME412	Competence	1
k. The application of the second law of thermodynamics to the design process	ME328	Competence	1

l. The application of the fundamentals of heat transfer in the analysis of thermal systems	ME412	Competence	1
m. Linear system modeling and analysis of 2 DOF system responses	ME491	Awareness	2
n. The application of the second law of thermodynamics to the analysis of energy components including 1. Steam and gas turbines 2. Compressors and pumps	ME321	Competence	1
e.4) A fluency in both English and SI units and an ability to translate between them (Note: added 9/08)	ME101	Competence	2

[ABET-k] OU ME graduates will demonstrate an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Measurable Outcome Statements supporting ABET-k: modern engineering tools outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
k.1) Drafting skills for creating and interpreting manufacturing and assembly drawings, including the use of CAD tools to create 2D drawings and parts lists.	Prerequisite inventory in ME304	Competence	2
k.2) The ability to use CAD solid modeling software for engineering applications, including creating & assembling 3D models of simple engineering systems	ME351	Mastery	2
k.3) The ability to apply the concepts of geometric dimensioning and tolerancing for creating and interpreting manufacturing and assembly drawings	ME288	Competence	1
k.4) The ability to correctly use finite element analysis software, including the ability to correctly mesh a solid model, apply meaningful loads and boundary conditions, complete a linear static stress analysis, and interpret the results [**PI**]	ME451	Competence	2
k.5) The ability to use general engineering analytical software (for example MATLAB) as a tool for solution of common engineering problems (using capabilities such as numerical methods, vector analysis, and matrix operations)	MATH344	Competence	2
k.6) The ability to program and use CNC machines to manufacture simple parts	ME388	Competence	2

[ASME/ABET-a] OU ME graduates will demonstrate an ability to apply principles of engineering, basic science, and mathematics (including multivariate calculus and differential equations) to model, analyze, design, and realize physical systems, components or processes; and work professionally in both thermal and mechanical systems areas.

Measurable Outcome Statements supporting the ME program criterion and ABET-a: the fundamentals and professional work outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
a.1) An ability to apply knowledge of Linear Algebra			
a. The ability to complete standard matrix manipulations.	ME301	Mastery	2
b. The ability to use matrices for solving systems of linear equations	ME301	Mastery	2
c. The ability to define eigenvalues and eigenvectors and describe how they are used in engineering analysis.	ME491	Awareness	2
a.2) An ability to apply knowledge of Statistics			
a. An ability to complete a basic statistical analysis, including producing histograms, identifying probability distributions, and computing mean values, standard deviations, standard deviations of the mean, and confidence intervals **[PI]**	ME288	Mastery	1
b. An ability to define regression analysis and correlation coefficients, and an ability to use the method of least squared error to define a best-fit curve.	ME288	Mastery	1
c. A recognition of real-world engineering applications of statistical analysis	ME304	Awareness	2
a.3) An ability to apply knowledge of Numerical Methods			
a. The ability to define issues such as convergence, stability, computational cost, and error propagation as they apply to Numerical Integration and Differentiation.	MATH344	Competence	2
b. The ability to use numerical techniques to solve systems of initial value Ordinary Differential Equations [Competence; MATH344; Computers, programming and Simulation]	MATH344	Competence	2
c. The ability to use numerical techniques (such as Newton-Raphson) to solve systems of nonlinear algebraic equations [Competence; MATH344; Computers, programming and Simulation]	MATH344	Competence	2
d. A recognition of numerical solution methods for partial differential equations [Awareness; MATH344; Computers, programming and Simulation]	MATH344	Awareness	2
a.4) An ability to apply knowledge of Engineering Materials			
a. The ability to list major metal alloy systems and their physical characteristics	ME314	Competence	2
b. The ability to use binary equilibrium phase diagrams and phase transformation diagrams to determine phase composition, elemental composition, and microstructure	CHE231	Competence	2
c. The ability to explain heat treating principles, including: a. Quenching and tempering, b. Solutionizing and aging, and c. Annealing	ME313	Competence	2
d. The ability to define wear, fatigue, and fracture mechanics	ME304	Awareness	2

as they apply to engineering materials			
e. The ability to identify the uses and properties of engineering materials including metals, ceramics, polymers and composites.	CHE231	Awareness	2
a.5) An ability to apply knowledge of Engineering Mechanics			
a. Rigid body mechanics (Basic college-level Dynamics) i. Planar kinematics of rigid bodies, including general plane motion and relative motion analysis ii. Planar kinetics of rigid bodies, including drawing free body diagrams and writing equations of motion	ME224	Mastery	2
b. Deformable solid body mechanics (Basic college-level Strength of Materials) i. Elastic material behavior (Hooke's law) ii. 2D Principal stresses and strains (Mohr's circle) iii. Yield criteria (von Mises and Tresca) iv. Engineering and true stress and strain v. Beam theory vi. Column buckling	ME303	Mastery	2
c. Fluid Mechanics i. An ability to describe and apply Bernoulli's equation ii. An ability to describe and apply continuity equations	Prerequisite Inventory in ME412	Competence	1
d. An ability to interpret tensile test data	ME388	Competence	1
e. An ability to explain and calculate non-elastic (plastic) material behavior	ME314	Competence	2
f. An ability to calculate material deformation energy	ME314	Competence	2
a.6) An ability to apply knowledge of Manufacturing Methods			
1. An ability to identify basic manufacturing processes and to ascertain the types of products that are cost effectively produced with each process	ME314	Competence	2
2. A ability to describe the use of adhesives and mechanical fastening methods	ME304	Awareness	2
a.7) An ability to apply knowledge of Thermal Sciences			
1. Applying the first and second laws of thermodynamics in the analysis of energy components and systems, including 1.1 Vapor power cycles 1.2 Air power cycles 1.3 Refrigeration cycles 1.4 Psychometrics 1.5 Combustion	ME328	Competence	1
2. Applying the second law of thermodynamics in the analysis of availability	ME328	Competence	1
3. The fundamentals of convection, conduction and radiation	ME412	Competence	1
a.8) An ability to apply knowledge of the Fundamentals of			

Electrical Engineering			
1. Basic electronic measurements and DC and AC circuit analysis	Prereq inventory in ME388	Competence	**1**
2. Digital logic and digital devices, Basic signal processing (filtering, amplification, etc.), Basic microprocessor architecture, and the physical foundation of semiconductor	Prereq inventory in ME488	**Awareness**	**1**
3. An ability to explain the operation and performance characteristics of electric motors	ME488	Competence	1
a.9) An ability to apply knowledge of Fundamental Skills in Computer Methods by writing procedural and object-oriented computer programs, including: • classes and objects to define engineering systems. • functions to perform engineering calculations. • functions to simulate the performance of engineering systems. • functions to apply basic numerical methods such as root finding or numerical integration. • functions to read from or write to external data files.	ET181	Competence	2
a.10) An ability to model, analyze, design, and realize physical systems and components, and to work professionally in the Mechanical Systems Area	ME470/ 471/472	Competence	2
a.11) An ability to model, analyze and design thermal systems and to work professionally in the Thermal Systems Area	ME328	Competence	1

Outcomes that support objective 3: Graduate mechanical engineers with skills to perform in the work environment

[ABET-d] OU ME graduates will demonstrate an ability to function on multi-disciplinary teams

Measurable Outcome Statements supporting ABET-d: teamwork outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
d.1) An ability to work effectively on project teams in both member and leader roles, with team members who may have different backgrounds and technical skill levels. This may include the ability to: a. work cooperatively with others, b. analyze ideas objectively, c. encourage active participation of others, d. build consensus, e. deal productively with conflict, f. take leadership roles as the need arises to accomplish the group's objective [**PI**]	ME470/ 471/472	Competence	2

[ABET-f] OU ME graduates will demonstrate an understanding of professional and ethical responsibility.

Measurable Outcome Statements supporting ABET-f: professionalism outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
f.1) An appreciation for and an ability to promote safety and health in all aspects of the engineering profession			
1. An awareness of the need to consider safety in all aspects of the engineering profession	ME280	Awareness	1
2. Safety in testing and laboratory work, including awareness of Material Safety Data Sheets (MSDS) and the proper use of Personal Protective Equipment (PPE)	ME488	Competence	1
3. Safety during manufacturing and assembly, and product safety through Design For Safety or similar approaches **[PI]**	ME471/ 472	Mastery	2
f.2) An ability to evaluate ethical issues that may occur in professional practice	ME101/ ME470 combined activities	Competence	2
f.3) An ability to describe the importance of patents and intellectual property rights	ME470	Awareness	2
f.4) Interactions with industry and engineering professionals through industrial involvement in design projects and opportunities for participation in the co-op program, plant tours, and professional organizations such as ASME and SAE.	ME472	Awareness	2
f.5) An ability to identify the applicable professional codes of conduct for engineers (such as the "Code of Ethics for Engineers" of the National Society of Professional Engineers and the "Canons of Ethics for Engineers" of the Engineer's Council for Professional Development)	ME101	Awareness	2

Notes:

- ET181 includes discussion of copyright and plagiarism issues
- Learning Communities - most students get ethics modules / activities
- Representatives from Environmental Health and Safety (EHS) will be asked to make presentations in ME280

[ABET-g] OU ME graduates will demonstrate an ability to communicate effectively

Measurable Outcome Statements supporting ABET-g: communication outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
g.1) Written and graphical communication skills appropriate to the profession of engineering, including:			
a. Writing and editing clear and effective engineering design reports, including technical content that is factually correct, supported with evidence, explained with sufficient detail, and properly documented [**PI**]	ME470/ 471/472	Mastery	2
b. Writing and editing clear and effective laboratory reports, including the creation of "professional quality" graphics for figures, tables, plots and charts.	ME388	Mastery	1
c. An ability to synthesize a large project report in the form of abstracts and executive summaries	ME470/ 1/2	Mastery	2
d. Documenting project work properly in a design notebook	ME470/ 1	Competence	2
e. Documenting experimental data properly in a lab notebook or on lab data sheets	ME488	Competence	1
g.2) Oral and visual communication skills appropriate to the profession of engineering, including:			
a. Preparing and making clear and effective formal presentations, including the preparation of "professional quality" visual aids [**PI**]	ME470/ 1/2	Mastery	2
b. The ability to participate in technical discussions	ME470/ 1/2	Competence	2

[ABET-i] OU ME graduates will demonstrate a recognition of the need for, and an ability to engage in life-long learning

Measurable Outcome Statements supporting ABET-i: life-long learning outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
i.1) An ability to find, evaluate and use resources to learn independently [PI]	ME471	Competence	2
i.2) A recognition of the need to accept personal responsibility for learning and of the importance of lifelong learning	ME471	Awareness	2
i.3) An ability for self evaluation, leading to improvement	ME470/ 1/2	Competence	2

Notes:

In ME470/471/472 students practice lifelong learning through independent student research and through the use of active listening and interviewing skills to gather information verbally from customers, vendors and design "experts".

Outcomes that support objective 4: Graduate mechanical engineers who are informed and aware of contemporary issues and the impact of engineering on society

[ABET-h] OU ME graduates will have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.

Measurable Outcome Statements supporting ABET-h: global and societal outcome OU ME graduates will demonstrate:	Tollgate Course	Performance level	Area of Expertise Group
h.1) An understanding of the influence of science and technology on civilizations and an ability to explain how science and technology have been applied to the betterment of humankind	ME101	Competence	2
h.2) An appreciation of engineering integration with business (market awareness, customer satisfaction, quality, continuous improvement, profit, mission/vision/core values, ...)	ME380	Awareness	2
h.3) An awareness of international standards and quality standards	ME380	Awareness	2

Notes:

- ME313 includes a discussion of global trends in manufacturing industries
- All students meet the General Education Requirements 16 hours of courses covering humanities, social sciences, fine arts, and cross-cultural perspectives
- Students in ME470/471/472 participate in discussions of the potential societal impacts of their design projects, and they identify government agencies, regulatory bodies, codes and standards that govern the global, societal, and environmental impact of their design projects.
- Speakers and topics in Mechanical Engineering Colloquium I and II (ME280 and ME380) address these issues from various perspectives.

[ABET-j] OU ME graduates will demonstrate a knowledge of contemporary issues.

In order to demonstrate achievement of the global and contemporary - contemporary issues outcome (ABET-j), OU ME graduates will demonstrate	Tollgate Course	Performance level	Area of Expertise Group
j.1) An awareness of the impact of energy systems on the global environment, including topics such as air pollution, climate change, environmental regulations, renewable energy, clean coal technology, and the hydrogen economy. **[PI]** as soon as practical)	ME328 (transition to ME380)	Awareness	1

Other Places where the global and contemporary - contemporary issues outcome is addressed.

ME321 (& the ME388 Stirling cooling lab): Discussions of energy issues such as renewable energy and Freon elimination, and the identification of local industries which are world leaders in energy technology.

Fundamentals & Service Courses - Detailed Outcomes

The following list of outcomes for our service courses provides a guide for curriculum development and improvement. Since these fundamentals are all applied and assessed at a higher level within our own program, direct assessment evidence for these outcomes is not necessary. We will use prerequisite inventories and prerequisite skills assessments as necessary.

a.1) Mathematics

a) Calculus and Analytic Geometry

Mastery of:

1. Basic differentiation skills, including the use of the product rule, the chain rule, and the ability to compute partial and total derivatives
2. Basic integration skills, including graphical interpretation of integrals and integration by parts

Competence in:

3. The use of numerical series and approximations
4. Linearization (Taylor Series)
5. Basic skills in 2D and 3D analytic geometry

Service Course(s): MATH 263A/B/C/D [Prerequisite Inventory for 263A in ME301, and for 263C in CE220]

b) Differential Equations

Mastery of:

1. The ability to analytically solve linear initial value problem ODEs, including homogeneous & non-homogeneous solutions
2. The ability to analytically solve boundary value problem ODEs

Competence in:

3. The use of Laplace Transforms to analytically solve ODEs

Service Course(s): MATH 340 [Prerequisite Inventory in ME491]

a.2) Physical Sciences

a) Chemistry

Competence in:

1. Basic college-level Chemistry, including the periodic table, inorganic chemistry, and chemical reactions

Awareness of:

2. Organic structures

Service Course(s): CHEM 151/152

b) Physics

Competence in:

1. Basic college-level Physics, including Newtonian Mechanics; the principles of force, work and impulse-momentum; electricity & magnetism, waves and optics.

Service Course(s): PHYS 251/252/253

Attachment 1a: Performance Level Definitions

To define the required performance for each measurable learning outcome

1. Awareness/Exposure

- The awareness level corresponds to the "Knowledge" level in Bloom's taxonomy, and the "Worth being familiar with" category in *Understanding by Design*.
- Learning activities related to the outcome must be a required part of the course, but there is no minimum performance requirement for the students to meet.
- To assess student achievement of awareness with respect to an outcome you must document that all students have been exposed to information related to the learning outcome – for example you might document that all students attended a presentation on a topic related to the outcome and wrote a short summary on the topic.

2. Competence/Ability

- The competence level corresponds to the "Comprehension and Application" levels in Bloom's taxonomy, and the "Important to know and do" category in *Understanding by Design*.
- Learning activities related to the outcome must be a required part of the course, and there must also be clearly defined assessment activities with clearly defined minimum performance requirements that the students must meet to demonstrate ability with respect to the outcome.
- Student achievement of competence/ability for an outcome can be demonstrated by defining an acceptable level of performance on an appropriate assessment activity and directly assessing whether or not each student meets or exceeds that level of performance. For example, to demonstrate effective oral communication you could set the assessment activity as a formal presentation and you could set several performance criteria including items like "speaks clearly and with sufficient volume" and "responds effectively to questions and comments", then when each student makes their presentation you can assess with a simple yes/no rating whether or not each student meets each performance criteria and you can track the percentage of students who met all (or some acceptable number) of the performance criteria. This percentage should be recorded and used for comparison with previous and future results for this outcome to track continuous improvement.

3. Mastery/Understanding

- The mastery level corresponds to the "Analysis, Synthesis, and Evaluation" levels in Bloom's taxonomy, and the "Enduring understanding" category in *Understanding by Design*.
- Learning activities related to the outcome must be a required part of the course, there must be assessment activities with clearly defined minimum performance requirements that the students must meet to demonstrate both ability and understanding, there must be significant formative feedback given to the students on the learning activities and/or assessment activities, and there must be some required reflection to force the students to synthesize and process information related to the outcome.
- Student achievement of mastery for an outcome can be demonstrated by defining an acceptable level of performance on an appropriate assessment activity (the activity must extend beyond doing to include evaluating) and documenting that all students who passed the course met or exceeded that level of performance. For example, an appropriate assessment activity could be a project that requires the student to solve an open-ended problem by synthesizing information learned in other contexts and critically evaluating the result rather than merely reporting an answer, and a mastery learning procedure could be followed requiring recycling until understanding is clearly demonstrated. For additional ideas on assessing understanding see *Understanding By Design* (in particular see the Rubric for the Six facets of understanding - Explanation, Interpretation, Application, Perspective, Empathy, Self-Knowledge - on pages 76-77).

*** From Bloom's Taxonomy** *(For Reference)*:
Evaluation (Employment of internal or external criteria for making critical judgments); **Synthesis** (Combining elements into a whole); **Analysis** (Breaking down a problem into its component parts); **Application** (Solving new problems with familiar principles); **Comprehension** (Translation of a concept into a somewhat different form); **Knowledge** (Recall of factual material in similar form)