White Paper on “Design” in Ceramics, Materials, Metallurgical and Similarly Named Engineering Programs

The purpose of this White Paper is to provide clarification and examples for interpretation of the ABET criteria as they relate to materials programs, but in no way is it intended to supersede the ABET criteria. It remains the responsibility of individual programs to demonstrate that the ABET criteria are met. Programs retain the flexibility to define, develop and demonstrate innovation in their curricula, educational objectives, outcomes and assessment methods, particularly as they relate to design.

Definitions and Criteria

The 2022-23 *ABET Criteria for Accrediting Engineering Programs* discuss “design” in several places, which are identified with *italics* in this document (***bold italics*** emphasizes key ABET terms and phrases).

The ABET engineering criteria include definitions of ***basic science***, ***engineering science***, and ***design*** that show a progression from fundamentals to application and utility:

Basic Science *– Basic sciences are disciplines focused on knowledge or understanding of the fundamental aspects of natural phenomena. Basic sciences consist of chemistry and physics and other natural sciences including life, earth, and space sciences.*

Engineering Science – *Engineering sciences are based on mathematics and basic sciences but carry knowledge further toward creative application needed to solve engineering problems. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other.*

Engineering Design *– Engineering design is a process of* ***devising a system, component, or process*** *to meet desired needs and specifications* ***within constraints****.* ***It is an iterative, creative, decision-making process*** *in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances. For illustrative purposes only, examples of possible constraints include accessibility, aesthetics, codes, constructability, cost, ergonomics, extensibility, functionality, interoperability, legal considerations, maintainability, manufacturability, marketability, policy, regulations, schedule, standards, sustainability, or usability.*

Criterion 3. Program Outcomes

. . .

2. *an ability to apply engineering* ***design*** *to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors*

…

6. *an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*

Criterion 5. Curriculum

…The curriculum must include:…

(b) a minimum of 45 semester credit hours (or equivalent) of engineering topics appropriate to the program, consisting of engineering and computer sciences and engineering design, and utilizing modern engineering tools.

…

(d) a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work.

<u>The Program Criteria for Ceramics, Materials, Metallurgical and Similarly Named Engineering Programs:</u>

The curriculum must include topics that:

a) underlie the four major elements of the field: (i.e., structure, properties, processing, and performance) related to material systems, as appropriate to the program title;

*b) **employ selection and design of materials**, processes, or a combination of materials and processes; and*

c) apply experimental, statistical, and computational methods to materials problems.

Introduction

Understanding and interpretation of design as specified in ABET EAC Criteria 3 and 5 vary widely among ABET leaders, program evaluators, faculty, and department chairs involved with materials programs. A consequence of this diversity in points of view is that it is difficult to devise meaningful and challenging capstone design experiences for students in materials programs that will, with some consistency, satisfy program evaluators. This topic and the ABET accreditation process in general were discussed by the chairs of Materials departments attending the May 5-6, 2005, and September 26, 2005, meetings of the University Materials Council (UMC)[1]. Based on these discussions, a white paper was written to develop a more consistent and constructive interpretation and understanding of "design" in the context of ABET EAC criteria and of objectives, outcomes, and resources of the nation's undergraduate materials programs. Updates to this white paper use Calibri font, and they reflect similar discussion from 2016-2018 among the same groups of people.

In discussing ABET accreditation criteria and procedures particularly as they apply to "design," UMC members noted the great diversity in the nation's materials programs, with many now including some or all of the following areas: biomaterials, ceramics, electronic materials, metals and polymers, along with nanotechnology and computer simulation and modeling. In addition, materials design incorporates both "design of" and "design with" materials, which makes these programs different from those in most other engineering disciplines. These factors, along with the need to prepare future engineers for success in a global job market, warrant a broad and flexible interpretation of the ABET EAC Criteria 3 and 5 for design.

To help materials programs develop innovative and challenging design experiences that satisfy ABET accreditation criteria, the UMC offered proposals to TMS and NICE to improve training and guidance of program evaluators and materials program faculty. The white paper and proposals were reviewed by the

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[1] The UMC is the organization of heads and chairs of materials departments, who are responsible for leading, developing and overseeing educational programs to prepare the nation's future generations of materials scientists and engineers for productive, lifelong careers.

TMS[2] and NICE[3] Accreditation Committees, and after revisions to incorporate suggestions from committee members, the White Paper was endorsed by both TMS and NICE in 2005. A similar process took place in 2019. The document has been further updated to reflect changes in definitions and program criteria.

Understanding and Interpreting "Design" in Criteria 3, 5, and the Program Criteria for Ceramics, Materials, Metallurgical and Similarly Named Engineering Programs

1. "Design" in Criteria 3, 5, and the Program Criteria for Ceramics, Materials, Metallurgical and Similarly Named Engineering should be interpreted by program evaluators and materials program faculty in a broad context.

   The second sentence in the definition of design provides a perspective that greatly increases the breadth of possibilities for an effective design experience that can be assessed objectively: *Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances.* In evaluating students' abilities "to apply engineering design to produce solutions that meet specified needs" and students' preparation through a "culminating major design experience based on the knowledge and skills acquired in earlier course work," the "design" may include

   - design and evaluation of a material for a specific application;

   - reverse engineering and design improvements involving materials;

   - design and evaluation or optimization of a materials processing method;

   - design of a method for determining, controlling, or selecting materials characteristics or properties;

   - design of a process to assess failure, quality, or consistency of a manufactured product;

   - computational design of a material with specified properties, or of a manufactured product with specified material constraints;

   - performance of a series of documented and evaluated design activities in these or other areas throughout a student's undergraduate program and continuing into the senior year as a ***culminating design experience*** that provides experience at least equivalent to a single, senior-level design project; or

   - other design activities that satisfy requirements in ABET EAC Criteria 3 and 5, noting that it does not require physical material or experiments (though it should depend on prior course work that does involve physical material and experimental work), but there must be evidence of ***an iterative, creative, decision-making process***. While it could involve physical material, and laboratory experiments, it could also be a design experience that is only "on paper", or based upon computational assessments. It is **not** a literature survey,

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[2] TMS is the professional society with primary responsibility for materials, metallurgical and similarly named engineering programs within ABET.

[3] NICE is the professional society with primary responsibility for ceramics and similarly named engineering programs within ABET.

but a literature survey could provide the basis for an iterative, creative decision-making process that could enable a new product or process.

2. Training materials for program evaluators and faculty involved with accreditation for Ceramics, Materials, Metallurgical and Similarly Named Engineering Programs should include discussion of breadth and diversity of “design” that satisfy the design requirements of Criteria 3 and 5, and should provide ***examples*** of possible design activities for materials students.

   For possible design activities to satisfy ABET EAC Criteria 3 and 5 design requirements, they must incorporate consideration of “constraints” that are appropriate to the activity, for example strength, weight, cost, lifetime, and environmental impacts might be important in “design and evaluation of a material for a specific application,” in “reverse engineering and design of improvements involving materials,” or in “design and evaluation of a materials processing method.” Constraints in “design of a method for determining, controlling, or selecting materials characteristics or properties” might include the accuracy or precision needed in determining properties, economic and time trade-offs in different measurement methods, choice among different equipment available for the work, and health and safety concerns in setup and operation of the equipment. “Design of a method for determining material properties,” might satisfy the Criterion 3(6) “*an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*” as well as Criterion 5. In the materials discipline, design and conduct of experiments, “within constraints,” can be viewed as design of a “process” that satisfies Criterion 5 in the same way as design of a system or component, if design of the experiment has the usual defining characteristics of “design” in Criterion 5, being an “***iterative, creative, decision-making process*** *in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions.*” Materials modeling and simulation are increasingly important in materials science and engineering, and some design experiences may be conducted entirely through computational design of materials.

   Both program evaluators and program faculty should recognize that it is the responsibility of each educational institution to ensure and demonstrate that its program meets the requirements of the ABET Criteria 3 and 5 with regard to “design” and in other areas, but that the design requirements of ABET Criteria can be met in a variety of ways, which may differ widely among different programs and even for different students within particular programs.

Examples of Design Experiences in Materials

These examples are provided as a guide to different types of projects that could satisfy the Criterion 5 design requirement.

1. **Participation in a broad-based multi- and inter-disciplinary team project with a significant materials and design component, although the project outcome may not be a materials component, system or process.** For example,

   - Solar car, concrete canoe building or similar projects.
   - Other opportunities are available at some institutions through student-led organizations such as Engineers Without Borders.

2. **Design, select and evaluate the application of materials for a specific application**

   - Keramos/ACERS ceramic cup or putter design competition;

- failure analysis of a component and development of an improved material, process, or design for the component;
- design of processes for heat treatment of an alloy or deposition of a thin film to control properties for a specific application;
- process design to control morphology in injection molding of crystalline polymers;
- design of processing of polymer blends for optimum properties;
- design and development of scaffolds for tissue engineering;
- design and cost modeling for replacing a component with one fabricated with an alternative material.

3. **Reverse engineering of a component and design of a better component through selection of different materials.**

4. **Design of a process to assess failure, quality, or consistency of a manufactured product**

   In this scenario, the focus of the design is to develop a systematic and/or strategic process to gain desired information, of which the focus could be a failed part in which flaws or variations in the manufacturing process are considered, or a way to determine if failure exceeded the specifications for the part, or a way to assess if the manufacturing process produces products that meet specifications in order to provide necessary feedback control. Such a project could highlight interrelationships between structure, property, processing, and performance.

5. **Computational design of a material with specified properties, or of a manufactured product with specified material or process constraints**

   Such projects could be done at the atomistic scale, as in designing a compound where a specific material property or balance of properties is sought, or at the finite-element modeling scale, e.g. for a constrained shape where material selection (or process history) provides the primary means to meet the desired property or other specification. Some of the structure, property, processing, and performance interrelationships could provide a basis for assessment or constraint of the design.

6. **Design, conduct and perform a custom project**

   The student(s) would identify a problem and propose a work plan to solve the problem. Details of the requirements would be established by each institution but may include a proposal plan with milestones and go/no-go decision points identified, progress reports (written and/or oral), lectures and seminars on conducting and managing a research program, and final written and oral reports. A team experience could be satisfied by this type of project. Examples of “team members” may include graduate students and post docs, industrial scientists and engineers, in addition to the undergraduate design student. These team members could be cited or acknowledged in a thesis or report for a project that is primarily the work of a single student.

   This problem could also involve a properly constituted and framed research problem, which may be performed during an industrial internship, a summer program, as part of a co-op or in a scientific research group at a University, but there must be evidence of ***an iterative, creative, decision-***

making process. In defining such a project, the second sentence of the definition of design provides valuable guidance to enable objective demonstration of the design content in the project.

7. Design Portfolio

Materials science and engineering students may be involved in design-related activities, including co-op, industrial summer internships, and summer research programs, from the beginning of their degree program and continuing into their senior year with a culminating design experience. The design portfolio would be presented to the program visitor and a summary provided to demonstrate that all design requirements of Criteria 3 and 5 and Program Criteria are met.