

## **AC 2007-1905: SUPPLEMENTARY LEARNING METHODS IN MATERIALS SCIENCE EDUCATION**

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# Supplementary Learning Methods in Materials Science Education

## Abstract

The mechanical engineering curriculum in our department contains two required materials courses, supplemented with several technical elective courses dealing with the state of the art in advanced materials. We are involved in the introductory materials science course and in the technical elective courses. A newly-developed technical elective course *Thin and Thick Films* is designed for students seeking to learn about one of the most important branches of materials science, namely the science and technology of materials in the form of films. This paper reports our experiences and approaches in achieving the course objectives more effectively by means of using supplementary learning methods including pre-quizzes, multidisciplinary learning through extramural speakers and off-campus lab visits, and service learning.

## 1. Introduction

Teaching is an unnatural act, an incursion on another person's learning-in-progress. In particular, demonstrating the gee-whiz applications for new materials in trendy commercial products that are smaller or faster or just plain better-designed is the glamorous side of teaching materials science. The challenge lies in delivering along with the applications the underlying science and math principles needed to understand materials topics that strike terror at first glance in many novices' hearts, such as crystal structure and phase diagrams. Therefore, it is necessary for the study material to be approachable, yet interesting. It is truly challenging to keep the instruction from getting boring and yet accomplish the course objectives in their entirety. This paper discusses our experiences and lessons learned by the introduction of supplementary learning and assessment methods. These include teaming of undergraduate with graduate students, multidisciplinary learning, and the use of a 'Materials Concept Inventory', service learning through providing tours and lectures to K-12 students and prospective college students as well as outreach visits to local schools. The outreach provided them opportunities to showcase their knowledge of thin film technology and application of thin films based devices in day-to-day life. The students have personally expressed their satisfaction with the course content and objective. This conclusion is also supported by the data from the "Student Course Content Evaluation" survey we use for ABET outcomes assessment in the ME curriculum.

## 2. Course Description and Learning Methods

**2.1 Materials Science Course:** There are presently two required courses in materials science for all mechanical engineering majors. The first course, Materials Science (MEEN 260), is offered at the sophomore level. This is a two-credit introductory course on materials science and also serves as a service course for chemical and industrial engineering students. The second course, namely MEEN 460: Modern Engineering Materials, is a three-credit advanced course on the engineering rather than the science aspects of materials and taken by students at junior and senior levels majoring in Mechanical Engineering. This paper presents our experiences with the MEEN 260 course. The foremost objective of this course is to introduce fundamental concepts in materials science by making students learn material structure, how structure dictates properties, and how processing can change structure. The course also intends to enable the students with

knowledge and understanding to help use materials properly and to realize new design opportunities with materials.

The MEEN 260: Materials Science course is taught in two sections and both the sections have recently adopted the second edition of “Materials Science and Engineering: An Integrated Approach” by Callister<sup>1</sup> as opposed to the previously-used “Materials Science and Engineering: An Introduction,” by Callister<sup>2</sup> (Sixth Edition). We adopted the current book due to the better organization of the chapters in terms of contents.

Course Assessment: The course learning objectives, listed in Table 1 and course outcomes, listed in Table 2, were assessed using both indirect and direct assessment. The indirect assessment involved student surveys in groups of four. These tables also list whether remedial action is needed on the part of instructors to improve the course. We plan to enhance the students’ knowledge of contemporary issues by dedicating two lectures and one quiz on nanomaterials and encourage students to engage in student chapters of professional societies such as ASME so that they are exposed to the importance of professional and ethical responsibilities.

Table 1: MEEN 260-Materials Science Course Learning Objectives

<b>Student response averages (0-3 scale)</b>	<b>Survey question:</b> To what extent did this course meet each of the course learning objectives stated below?  <b>Student groups responded using the following scale:</b> Strong 3   Moderate 2   Weak 1   None 0	<b>Action needed? (Y/N)</b>
2.75	To introduce fundamental concepts in materials science by making students learn material structure, how structure dictates properties, how processing can change structure	N
3.00	To enable the students with knowledge and understanding to help use materials properly	N

Table 2: MEEN 260-Materials Science Course Outcome

<b>Student response averages (0-3 scale)</b>	<b>Survey question:</b> To what extent did this course contribute to your abilities in the areas listed below?  <b>Student groups responded using the following scale:</b> Strong 3   Moderate 2   Weak 1   None 0	<b>Action needed? (Y/N)</b>
2.75	Ability to apply knowledge of science and engineering.	N
2.37	An understanding of professional responsibility and ethical responsibility.	N
1.75	Knowledge of contemporary issues.	Y

The direct assessment component involved evaluating the students based on their performance in tests (quizzes, midterms, and finals). Since this course requires a minimum of C to pass, the performance of students obtaining D and F were not included in the outcome analysis, because

those students will be repeating the course. In some cases, quizzes were designed to assess the specific outcomes while in other cases particular questions were designed to test the specific outcomes. The following description of quizzes, mid term test and a specific question illustrate the assessment approach more clearly. Quiz 1 and 2 were designed to assess the knowledge of science and quiz 3 was designed to test the knowledge of engineering. Question 7 on the final examination was: “(a) Indicate the position of yield strength, tensile strength and fracture strength using a typical engineering stress-strain curve. Also sketch the geometry of the specimens at various points along the curve. (b) Draw schematically the five stages of fracture via cup-and-cone mechanisms.” This question requires an understanding of how materials fail and the boundaries of loading parameters for the safe usage of materials in various applications. It also requires an ability to investigate the reasons responsible for the catastrophic failure of materials. As seen from Figure 1, more than 90 % of the students secured a perfect score on this question.

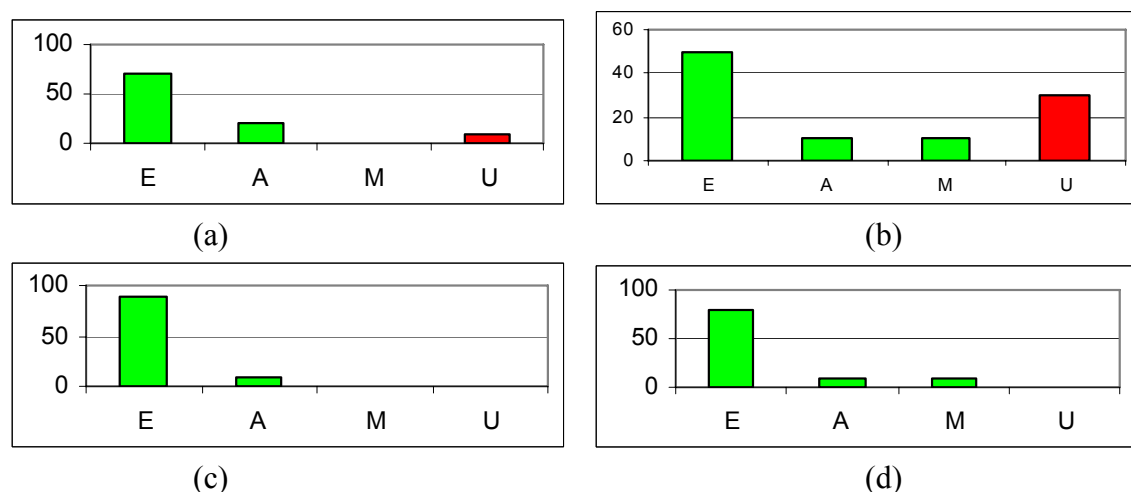


Fig 1. (a) Quiz 1 on periodic table and chemical bonding, (b) Quiz 2 on crystallographic directions and planes, (c) Quiz 3 on mechanical properties of materials, and (d) a question on fracture mechanics on the final examination. Scale: E (Excellent), A (Adequate), M (Minimal), U (Unsatisfactory)

In addition to evaluating the test and quiz performance of the students in tests, we have also employed a Materials Science Course Inventory (MSCI) as an assessment instrument. The course inventory was developed by Fink et al. [3]. The MSCI was distributed on the first day and on the last day of the class. All the copies of the inventory were picked up at the end of the first day class to make sure students did not have it to study from at the end of the semester. The inventory collected at the end of the last day of the semester was compared with the first day inventory (Fig. 2). The comparison was used to measure the gains in overall course content knowledge. It is clear from this figure that the course has benefited majority of the students by enhancing their knowledge of materials science. We are now planning to use the ‘knowledge gain score’ to restructure some of the course contents and to determine the topics of the course that require more attention and time in the lectures.

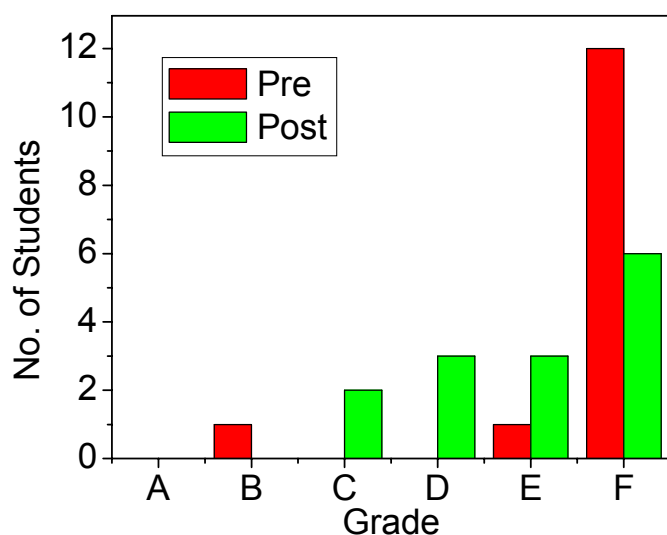


Fig. 2. Student performance in pre- and post MSCI test (Grading scale is A: 9-10, B: 8-9, C: 7-8, D: 6-7, E: 5-6, F:<5)

**Student Feedback:** Student feedback was collected via an online anonymous survey administered on the university's online course management system (Blackboard).

QUESTION: What are things you like about the class?

- The way the teacher asks group questions

- There are a lot of things that I like about this class. For one, my teacher brings models and food in to show examples of what we are working on regularly. Also, the teacher gives a lot of examples and notes in class that make it easier for students to understand. Last, but not least, the thing that I really like about the class is that it focuses on everything that I did this summer at an internship. I worked in the Materials Science & Applications Department and a lot of the things that I did there come up in class very often.

- Complex ideas displayed in everyday things we can relate to.

- The thing I like most about the course is that there are so many outside resources that the professors gives us to understand the material. The instructors also have a lot of office hours, and the TA is very helpful.

- I love the way that the instructor teaches the class. I actually learn things in class rather than depending on a tutor to explain.

- Being an IE major, I couldn't care less about material science.

- Very active and keeps my focus. It is also an interesting course.

- How it relates to things that I have run across in trying to figure out metals and their compositions. ie. forging metals for swords.

- Very interesting knowing why things are the way they are generally speaking. A new twist on chemistry or science in general.

**QUESTION: What is one thing you could do to improve the class?**

- working out more problems
- Create models and run tests for extra credit on my final grade, that would give the next students other visuals
- Nothing
- Make it a 3 hour course.
- I don't know
- More extra credit
- One thing that I could do to improve the course is make sure I read all the material before class.
- One thing I could do to improve the class is to try my best to know more than I do now before we start a new section in the book. That way, if my instructor asks me a question, or if one of my peers needs help understanding the material, I will be better equipped to handle the situations and be of some assistance.
- Be on time for class and be prepared
- Make sure that I make it to class everyday
- More credit hours so that we can take more time on topics. This class has tons of information and it's just not enough time to really get into like I would like to.
- The homework process
- Make it a three credit class because too much information is squeezed into only 2 days a week.
- I would say I have got all the help I needed in order for me to understand the subject clearly, but it would be better if there is a definite time and place for student instructors on a weekly bases, not only when exam time is approaching.

Modifications Made to Course: The two sections are taught independently and survey comments from both sections are discussed. In one of the sections, we have increased the number of quizzes to five compared to three quizzes in Spring 2006. This was done to increase student involvement and commitment to the course. Since the duration of the quiz was 10 minutes, conducting the quizzes did not interfere with the coverage of materials. We have also reduced the weightage of final exam to 30 % in the Fall 2006 from 45 % in Spring 2006. Though it is not clear to us which of these two approaches has contributed more to the better performance of the students at higher level (Grade A and B collectively) and lower failure rate, the data presented in Fig. 3 clearly shows that these approaches have a positive impact on student performance. The

improvement in student performance is thought to be associated with scope of instantaneous feedback to the students as well as instructor via quizzes.

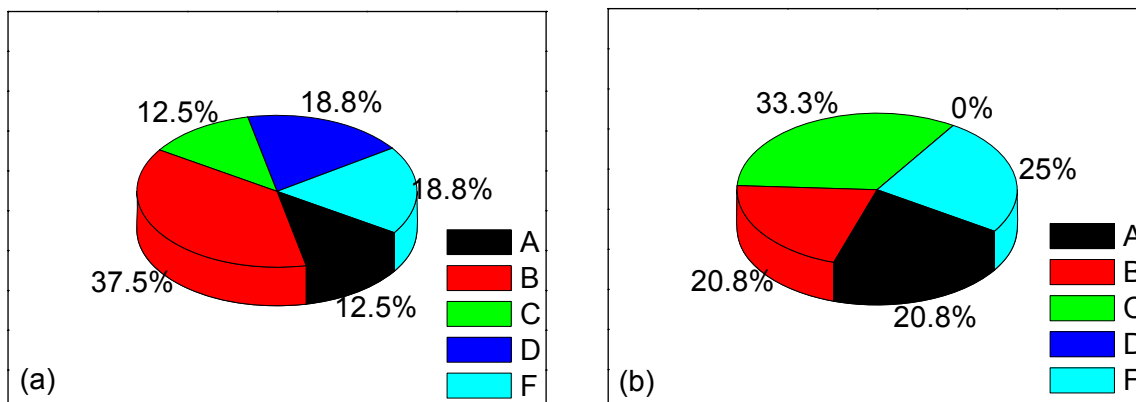


Fig. 3. Student performance in (a) Fall 2006 compared with (b) Spring 2006

In the other section, the instructor is creating an active learning environment via several methods. The methods are based on a workshop by Dee Finks in which he worked through his book “Creating Significant Learning Experiences”.<sup>3</sup> Based on this model, in-class and out-of-class experiences are planned. The other principle of course design that is utilized is the need for differentiation and variety in the types of learning activities. Out of class experiences included online home work, text book home work, interactive Materials Science website reviews, and online Blackboard quizzes before class. With the improvement in the Blackboard course management platform, these quizzes are found to be a more attractive tool. The quizzes, taken by students before the pertinent class lecture, have been shown to improve the student’s performance and comments from students are quite positive.

“I like how there are no pop quizzes. Even though I do not like to read and the chapters in the book are sometimes VERY long, I like how we have to take quizzes on Blackboard, though. That makes me read the book and therefore, get more out of this class.”

“I like the lectures because they are actually interesting and they give examples of real life situations which is what I like. I like the pre-quizzes because that means that I actually have to read the chapter before taking them.”

Another supplementary tool is the external links section of Blackboard. Each topic covered in the course has links associated and the students are encouraged through extra credit, or in-class questions to visit those sites. The classroom experience involves board lecture, team quiz-bowl type questions and partner work. At times PowerPoint slides are used to supplement the instructor’s board lecture and this also serves to keep the learning activities varied.

Instructors' Reflection: The course credit for majors should be increased to three hours to teach the material outlined in the handbook. If the expansion in credits is not possible, the instructors of both sections propose to limit the number of students to 30 in each section (expanding the current 2 sections to 3) and/or create a 3<sup>rd</sup> hour of recitation, so that appropriate attention can be paid to each student. Taking attendance each class and learning the names of the students is always important as reinforced by student comments.

**2.2 Undergraduate Technical Elective Course on Thin Films:** This is a newly developed technical elective course (less than three years old) in the Department of Mechanical and Chemical Engineering. The primary objective is to provide the students enrolled in this course a basic knowledge of thin film techniques and fundamental mechanism governing the nucleation and growth of thin films. The students also learn about the common techniques used for the determination of physical properties, especially in thin film form. This course also helps them to understand and interpret the reasons underlying the superior properties of thin film materials with respect to their bulk counterparts. The course has prerequisites of MEEN 260, MEEN 460 or Instructor's approval. Several books are referred to in the course.<sup>4-6</sup> There are two special features of this course. The course content includes the following topics: thin film nucleation and growth, fundamental of vacuum techniques including evaporation, sputtering, laser ablation, chemical vapor deposition and molecular beam, future directions in materials synthesis such as nanocluster deposition and nanoparticles self-assembly, relationship between deposition parameters and film properties, photolithography, physical and mechanical properties of thin films, application of thin film synthesis in microelectronics, nanotechnology and mechanical devices.

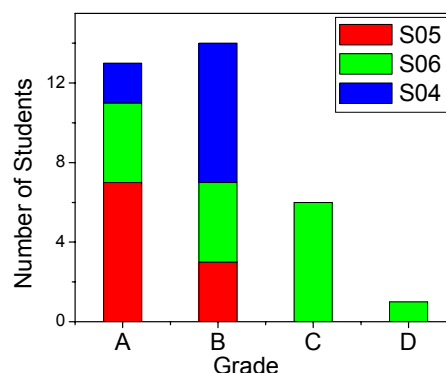


Fig. 4. End of course grades obtained by students in Thin Films course in three semesters

Student Performance: This course has been taught for three semesters in the department. A course on thin films was offered for the first time in the department at the 700 level during the fall of 2004 when only MS or Ph.D. students could enroll. The course was attended by 9 students (3 Ph.D. and 6 MS). Since no course on thin film was available in the department, we felt the need to offer the course on thin films at a level where both graduate and undergraduate students could register. Hence the course was modified to fit the senior undergraduate level and then offered at the 600 level in the spring of 2005. That semester, 12 students enrolled, of which 8 were undergraduate students. The end-of-course grade for the last three semesters is displayed in Fig. 4. In the spring of 2006, 16 students were enrolled in the class, with 4 MS and 12 senior undergraduate students.

Projects and Hands-on Experience: The students enrolled in thin film class get opportunities to work on advanced thin film deposition and characterization techniques such as pulsed laser deposition, x-ray diffraction, scanning electron microscopy, nanoindentation, and transport and magnetic measurements, etc (Fig. 5).





Fig. 5. Spring 2005 thin film class: hands-on experience

As a part of this course, each student was required to complete a project (Table 3). Depending on the number of students enrolled in the course, the project work involved working individually or in groups on an experiment and then writing an individual or a group report. At the end of the project, each individual/group was required to make an oral presentation on his/her/their work contribution and findings. The individual/group report was 10-15 pages in length with adequate technical content and literature survey.

Guest Lectures and Laboratory Tours: The special feature of this course was lectures by a limited number of guest speakers (maximum two). In Spring 2005, one of the guest speakers (from our Department of Electrical Engineering) spoke about the role of Molecular Beam Epitaxy in nanoscience and technology. The other guest speaker (Prof. Gerd Duscher, Department of Materials Science and Engineering, North Carolina State University) gave two lectures on micro- and atomic- level characterization of thin film and nanomaterials using TEM, STEM-Z, EELS. The entire class was taken to the NCSU campus where Dr. Duscher gave a tour to the NCSU-NSF Electron Microscopy Facilities (Fig. 6). The students had brief opportunities to mount samples and perform rudimentary operations on the TEM and STEM-Z instruments.

Table 3: Examples of individual and group projects in Thin Films course

Spring 2005: Individual project	Spring 2006: Group project
Thin Film Synthesis Semester Project	Aluminum Nitride Grown on Silicon for Semiconductor Applications (4 students in group)
Thin film Fuel Cell	PLD & Nano-Indentation TiN-Sapphire Substrate (4 students in group)
Titanium Nitride Thin-Film Hard Coatings	Mechanical Characterization of Aluminum Nitride Thin Film on Sapphire Substrate by PLD Method (4 students in group)
Novel Engineered Hard Thin Films: Titanium Nitride and Its Mechanical Properties	Pulsed Laser Deposition of TiN Thin Films on (100) Silicon (4 students in group)
Characterization & Synthesis of Novel Engineered Hard Thin Films	
Titanium Nitride (TiN) Tribological Coating	
Multilayered Thin Films	



Fig. 6. Thin Films class visit to NC State University: Prof. Gerd Duscher (left) demonstrating the operation of a STEM-Z system. The lab tour was followed by a classroom lecture by Prof. Duscher (right).

Community Service by students: The students enrolled in Thin Film course were provided with optional opportunities to participate in community service by giving tours/lectures to the K-12 students and undergraduate students visiting from local schools and colleges (Fig. 7). This provided them opportunities to showcase their knowledge of thin film technology and application of thin films based devices in day-to-day life.

**3. Adding value to the curricula:** Both the courses serve to achieve certain ABET outcomes very strongly. The students have personally expressed their satisfaction with the course content and objectives. This conclusion is also supported by the ABET style “Student Course Content

Evaluation” survey. Table 4 lists the areas that are covered in these courses. The results of outcomes assessment of Materials Science (MEEN 260) course and Thin Film Course (MEEN 660) are presented in Fig. 8 and Fig. 9, respectively. The scale of this data analysis is: Strong 3, Moderate 2, Weak 1, None 0. The course instructor was generally satisfied with the student participation in the class activities such as home work, tests, project work. However, the instructor was not satisfied with their level of home study. A large fraction of the students did not read the books or even the supplied lecture materials. The instructor will continue to encourage students to develop self-reading habit. Plans are also being made to arrange an industrial tour to some local companies engaged in advanced research and thin film technology.

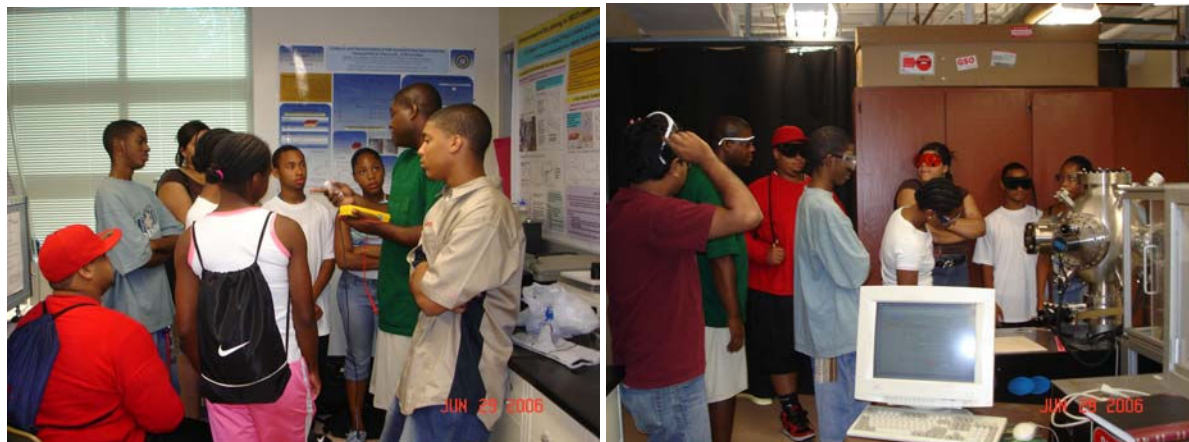


Fig. 7. Interaction with K-12 students and teachers.

Table 4. Student evaluation of course content for Thin Films course

Item no.	Survey question: To what extent did this course contribute to your abilities in the areas listed below?	MEEN 260	MEEN 660
	Student groups responded using the following scale:		
a.1	Ability to apply knowledge of mathematics		
a.2	Ability to apply knowledge of science.	x	x
a.3	Ability to apply knowledge of engineering.	x	x
b.1	Ability to design experiments.		x
b.2	Ability to conduct experiments.		x
b.3	Ability to analyze data.		x
b.4	Ability to interpret data.		x
f.1	An understanding of professional responsibility.	x	
f.2	An understanding of ethical responsibility.	x	
g.1	Ability to effectively communicate orally.		x
g.2	Ability to effectively communicate in writing.		x

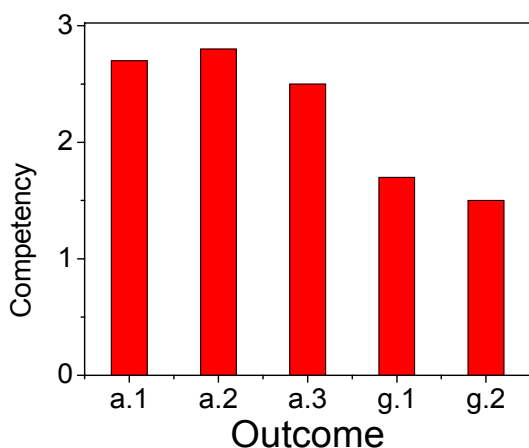


Fig. 8. Indirect assessment of accomplishment of program outcomes in 'MEEN 260: Materials Science' course (from student course content evaluation by 20 students in 6 groups).

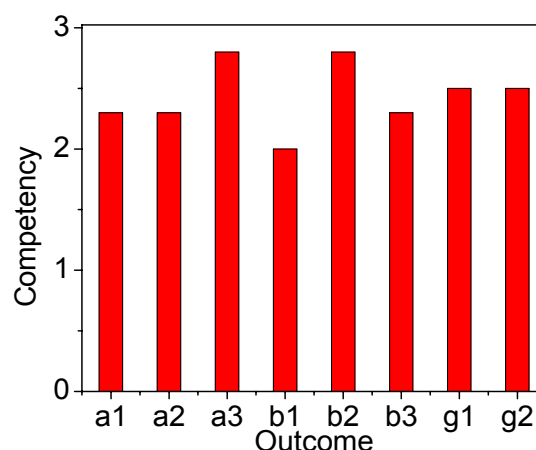


Fig. 9. Indirect assessment of accomplishment of program outcomes in 'MEEN 660: Thin Films' course (from student course content evaluation by 16 students in 4 groups)

#### 4. Conclusions

Several diverse approaches have been applied to the teaching of a sophomore-level materials science and a senior-graduate level thin films courses. These include pre-quizzes using course management software, team homework assignment, service learning, guest lectures, visits to extramural research labs, and hands-on experience with on-campus research projects. Many approaches have been demonstrated to be successful based both on student survey data ('indirect' assessment) and student performance data ('direct' assessment). The take-away lessons from these activities and assessments are fed back into the continuous process of course and curriculum improvement.

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