AC 2009-2228: IMPROVED MATERIALS SCIENCE UNDERSTANDING WITH BLACKSMITHING

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Improved Materials Science Understanding with Blacksmithing

Abstract

The methodologies used to teach engineering and science principles to students must adapt to effectively communicate these concepts based on the ethnicity, gender and previous educational experience. The current generation of students has matured in the modern computer world by learning and recreating with computer-based programs and games. The creativity abilities and learning methods associated with "hands-on" (kinesthesis) teaching methods have substantially decreased in recent years due to the availability and allure associated with computer based games and teaching programs. The Back in Black Blacksmithing project implemented at our campus is aimed at improving student understanding of the materials science concepts relating to composition, properties, processing and performance by applying kinesthetic learning techniques and the teaching some of the historic techniques of blacksmithing to engineering students in a materials engineering course. Gains in student conceptual understanding are measured through use of the Materials Concepts Inventory. Formative assessment of academic and cultural diversity include outreach demographics, focus groups, and learning styles of students involved in the program.

Background

The methodologies used to teach engineering and science principles to students must adapt to effectively communicate these concepts based on the ethnicity, gender and previous educational experience. The current generation of students has matured in the modern computer world by learning and recreating with computer-based programs and games. The creativity abilities and learning methods associated with "hands-on" (kinesthesis) teaching methods have substantially decreased in recent years due to the availability and allure associated with computer based games and teaching programs. The application of kinesthetic learning methods are not as utilized as they were in the past. Students no longer spend substantial amounts of time creating components with their hands, like previous generations, and this may be limiting their ability to comprehend many metallurgical engineering concepts such as the fundamental concept that relates material processing, microstructure, properties and performance. Figure 1 depicts the interconnected relationship between these metallurgical engineering concepts. One component of this proposal is to improve the student's understanding of these material science/metallurgy concepts by applying kinesthetic learning techniques and the teaching some of the historic techniques of blacksmithing to a limited number of students has shown early success with the student's final comprehension and application of these concepts to current industrial technologies.

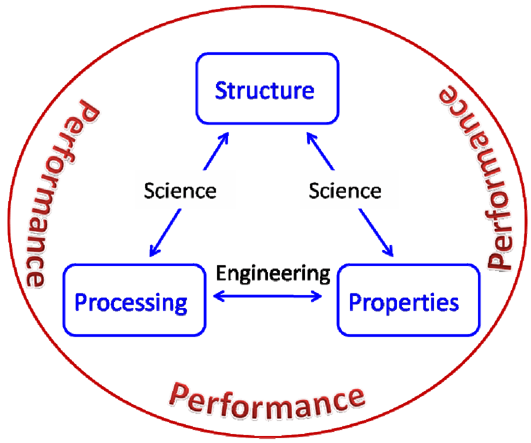


Figure 1. The Four Fundamental Metallurgical Engineering Concepts and Their Interrelationships.

Curriculum Modifications

The integration of some blacksmithing techniques into the undergraduate metallurgical engineering curriculum as a kinesthetic teaching tool will be implemented in several levels starting at the sophomore level. The first metallurgical/materials engineering courses available for SDSM&T undergraduates are sophomore level courses and they include two concurrent courses: a 3 credit hour lecture “Properties of Materials” (MET-232) and a 1 credit hour laboratory “Structure and Properties of Materials Laboratory” (MET-231). The next set of courses in the undergraduate curriculum sequence are “Physics of Metals” (MET-330) and the “Physics of Metals Laboratory” (MET-330L), and finally “Mechanical Metallurgy” (MET-440) and the “Mechanical Metallurgy Laboratory” (MET-440L). The curriculum modifications to these lectures and laboratories are described below.

Laboratory Modifications to Properties of Materials Laboratory

By adding traditional blacksmithing techniques to several laboratory modules of this course, the students will be getting a historical perspective of metallurgical engineering, obtaining a “hands-on” experience of how these blacksmithing techniques work, and obtain an improved understanding of the metallurgical interrelated concepts of processing, microstructure, properties and performance. As explained previously, some of the modern day terminology used in metallurgical engineering and materials science is directly related to the historic art of blacksmithing. Many of these terms will be reviewed in the course and the students are expected to have an improved understanding of the meaning of these terms because they will physically perform many of these techniques with a forge, anvil and hammer. Understanding the historic meaning of these metallurgical terms should improve the student’s understanding of the modern day technologies. The modern day processing techniques use powered equipment with much more process control and precision, however, the general engineering and science principles are the same. The students are expected to see and feel the changes taking place in the metals while using the blacksmithing techniques and this experience is expected to relate to an improve understanding of how different processing methods change the microstructure, how the resulting microstructural changes affect the material properties, and how the properties control the final performance of an engineering component. Evaluations of student homework problems and written reports will show an improved understanding and enthusiasm of this material.

Table 1. Changes in Properties of Materials Laboratory

Laboratory Module	Description of Changes in Properties of Materials Laboratory
Laboratory Module #1	This module has traditionally been "Introduction to Basic Statistical Computations" and this will be replaced by "Basic Forging Processes and Microstructures". The basic statistical computation portion of the laboratory will be integrated into a subsequent laboratory module. Laboratory Module #1 will include the basic safety requirements in the blacksmithing laboratory, an introduction to several blacksmith forging techniques, team development of a blacksmithing component utilizing several basic forging techniques, and identification of the forged microstructures with previously prepared metallographic samples. The goal of the laboratory will be able to have students perform several blacksmith forging techniques and identify the resulting microstructures. The kinesthetic application of blacksmith forging will enhance the students understanding of the resulting microstructures in the components that they fabricate.
Laboratory Module #2	This module has been "Rolling Mill Operations" and this will modified to "Cold Forming Processes and Strength Relationships". Students will take fully annealed iron and copper samples and cold forge the samples by hand with a hammer and anvil and by a semi-automated process using a rolling mill. During sequential reductions, the metallic samples will be hardness tested to determine the increased in strength due to the cold reduction processing. The kinesthetic application of cold reducing the thickness of the samples by hand will demonstrate to the students the increase in strength (hardness) of the samples due to the increased material flow resistance and the resulting increase in material hardness. Students will also learn the relationship between hardness and strength.
Laboratory Module #3	This module has been "Hardness Measurement" and this will be changed to "Metallographic Sample Preparation and Microstructural Evaluation". Metallographic sample preparation is a fundamental tool used in the field of metallurgical engineering and material science for microstructural phase identification. Students will take representative metal samples from Laboratory Modules #1 and #2 and perform the metallographic preparation techniques related to ASTM standards. The students will then photograph, identify the microstructures of these samples, and then write a report discussing the first three modules.
Laboratory Module #4	This module will remain "Tensile Testing" of aluminum and steel ASTM E8 tensile samples subjected to specific thermo-mechanical processing steps. The students will learn to operate the MTS tensile tester, generate stress-strain curves from the data, and calculate the strength and ductility properties.
Laboratory Module #5	This module will be changed to "Introduction to Basic Statistical Computations". The students will take the group and class hardness data from Laboratory Module #2, the calculated strength and ductility values from Laboratory #4, and learn to determine and plot the mean, variance and standard deviation. The students will conduct a library search to compare their experimental values to known literature values.
	This module has been a demonstration laboratory called "Metallography of Common

Laboratory Module #6	Alloys" where students were shown previously prepared metallographic samples and shown the different types of microstructures. This laboratory will be changed to "Heat Treatment and Microstructural Phase Changes" where student will take low, medium, and high carbon steel rods and heat treat them in the blacksmith forge by slow cooling, quenching, and tempering at various temperatures including sub-zero cooling. The students will perform hardness tests and metallographically prepare the samples for microstructural phase identification. The students will experience and see the results of heat treating red-hot metallic samples.
Laboratory Module #7	This module will remain "Quantitative Image Analysis" where they will learn to operate an image analysis system and learn to perform standard ASTM E112 grain size analysis and area fraction measurements. Students will perform these evaluations on selected samples from previous Laboratory Modules.
Laboratory Module #8	This module will remain unchanged as "Charpy Impact Testing" of steel and aluminum ASTM E23 samples.
Laboratory Module #9	This module will remain unchanged as "SEM Morphology Evaluation". Students are introduced to a scanning electron microscope and shown the differences in fracture surface morphology of the various Charpy samples from Laboratory Module #8.
Laboratory Modules #10 and #11	These two modules have been a two week laboratory called "Hardness Profile of Case Hardened Steel" where the students learn to use a microhardness tester and perform a hardness profile on a previously prepared case carburized gear tooth. They also photograph and characterize the microstructure through the case and core of the gear tooth. This laboratory will remain the same except during the first week the students will also learn how to pack carburize a wrought iron sample in the blacksmith forge. Using diffusion calculations and estimated forge temperatures, the student will estimate the approximate case depth and verify their estimates the following week with metallographic and microhardness measurements. The students will learn by experience how diffusion controlled alloying occurs.
Laboratory Module #12	This module has been "Jominy End-Quench Testing and Hardenability" where the students end quench a Jominy bar and measure the hardness profile. This will remain the same, except the students will also take 4-5 different alloyed steel bars and heat treat them in the blacksmith forge by slow cooling, quenching, and tempering at different temperatures and times. The students will perform bend tests and hardness tests and compare the changes in relative strength. The students will not only see and experience how the different alloyed samples are heat treated, but they will also feel how the strength changes due to the different heat treatment and alloy modifications.
Laboratory Module #13	This module will remain unchanged as "Measuring Mechanical Properties Using Strain Gauges" where the students learn to attach strain gauges to tensile samples and then determine the elastic modulus and poisson's ratio of two alloys

Physics of Metals Laboratory

In this junior/senior level course the students will learn more advanced blacksmithing techniques to further their comprehension and application of the fundamental metallurgical engineering concepts discussed previously. Students will learn the basic techniques involved in traditional forge welding of wrought iron steel components by changing the temperature of the components, applied forge forces, and chemistries of the flux materials. The students will then perform laboratory evaluations of the various forge weld combinations and correlate the different microstructures, hardness, and strengths. Using this hands-on approach and applying the engineering and science associated with modern day welding, the students will obtain an improved comprehension about modern material joining technologies and the resulting properties. In addition, students will also make Damascus Steel, or Mokume Gane, in the laboratory using a combination of low and high alloy steels and the traditional folding and forge welding methods. Microstructural evaluations will be performed on these components, as well as test pieces for tensile testing. This will give students an excellent hands-on example of material diffusion rates, interface bond strengths, composite material properties, and microstructural variation due to mechanical working and alloy segregation. A third module will be added to the laboratory that includes heat treatment processing of several different steel alloys in the forge. The students will use traditional blacksmithing techniques (austenitizing, quenching, tempering, etc.) to make a variety of typical microstructures for the alloys. Then, the students will use this information to design heat treatment processes that result in microstructures with a specific combination of properties for a series of engineering components. Through these hands-on laboratory experiences, the students will obtain an improved comprehension and application between processing, microstructure, properties, and performance.

Outreach

Outreach activities included a focus on high school students and on-site visits by B.S.-level student ambassadors and faculty to selected pilot schools. As part of this outreach activity a Back-in-Black mobile trailer was fabricated to provide a 20' x 8' footprint. Roughly 50% of the trailer area contains traditional blacksmithing equipment (hammers, forges, anvils), while the remaining area contains equipment associated with a traditional metallographic laboratory. All of the equipment is used within the B.S. level program but is portable for outreach used. In addition, campus students can participate in a weekly hammer-in which allows students to create special designs (branding irons, knives, jewelry, etc.) of their own interest. Student designs were showcased in an APEX Art Gallery exhibit during Engineers Week.

Assessment

Primary objectives for the program included the following:

- The outreach program will increase student recruitment and retention, particularly with regards to women and Native American students.
- Connecting elements of the program through blacksmithing operations will provide students with a better understanding of metallurgical engineering concepts and their interrelationships.
- The program will more effectively address diverse learning needs by allowing students to construct knowledge through a variety of creative and collaborative experiential opportunities.

Outreach Program

The complete outreach program has been active for two years; however, the first year was a learning experience for the faculty and the program has only been effective for student outreach for roughly a year. The overall student enrollment at SDSM&T has been flat or decreasing slightly decreasing for a few years, as well as the number of students majoring in Metallurgical Engineering. During the past year there has been an increase in the number of students majoring in Metallurgical Engineering (+17.2%) and a substantial increase in the number of female/minority students majoring in Metallurgical Engineering (+66.6%), as shown in Table 2. We attribute much of this increase in enrollment to the outreach activities. To date the number of Native American students majoring in Metallurgical Engineering has not changed, however, outreach activities are continuing in this area.

Table 2. The percent change in enrollment at the SDSM&T and the percent change in undergraduate students majoring in Metallurgical Engineering.

Percent Change in Enrollment		
Student Group	Fall 2006/2007	Fall 2007/2008
SDSM&T (Total Campus)	-5.4%	+7.3%
SDSM&T (Female/Minority)	+4.4%	+4.2%
MET (Total)	-4.9%	+17.2%
MET (Female/Minority)	-14.3%	+66.6%

Concept Inventory: Due to the one year implementation, preliminary assessments included use of the Materials Concept Inventory[1] (MCI) and an increased awareness of the metallurgical engineering opportunities available in the region. The MCI is a new instrument for this campus and was implemented as part of this program. Consequently, baseline data is not available. Further, course enrollments preclude comparison of a control and experimental group. However, a pre and post materials concept inventory was administered in selected courses in the fall of 2008 and again in the spring of 2009 after students had an exposure to the new course modules. Pre and Post average percentage scores for students are shown below in Figure 2.

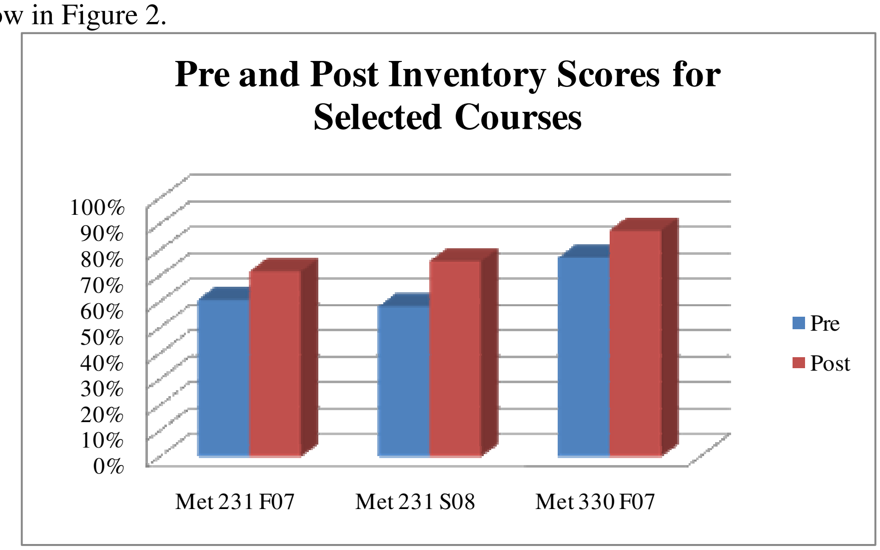


Figure 2. Average Percentage Score Received on the Materials Concept Inventory

Figure 2 indicates students tend to better understand fundamental concepts as they mature through the program as well as having received better conceptual understanding of fundamentals through reorganization of laboratory components and the Back in Black.

A question by question comparison was made between pre and post inventories in the three courses categorized by the four fundamental concepts and is shown below in Figure 3. Average scores for the pre inventory were calculated for each question by using a weighted arithmetic average across all three courses. Similarly, a weighted calculation based on the number of students completing the inventory was used to calculate an average post inventory score across all three courses.

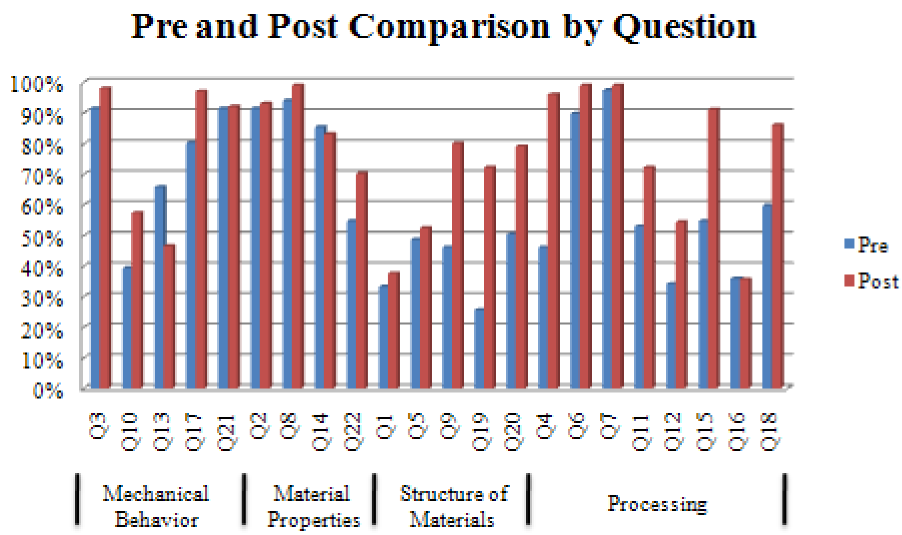
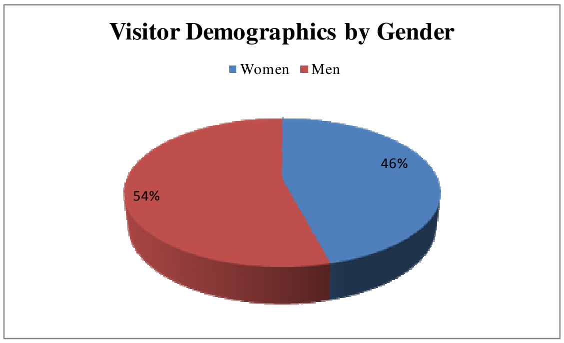


Figure 3. Question by Question Comparison from the Four Offerings of the MCI

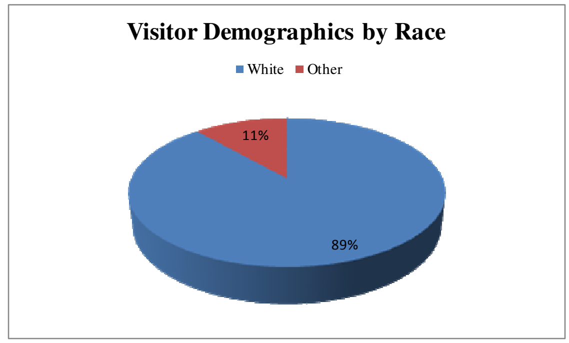
With the exception of concept 13 (impact loading), Figure 3 indicates that conceptual gains were made as students progressed in the curriculum. Figure 3 also indicates that while students made gains in all fundamental concept areas, the largest gains were made in the areas of structure of materials and processing. Average gains for mechanical behavior, material properties, structure of materials, and processing across category questions are 4.5%, 5.0%, 23.5%, and 20.3% respectively with gains in the latter two areas being both practically and statistically significant.

Focus Groups: Three focus groups consisting of three to five students each was conducted in April of 2008. Student groups were selected from an upper level metallurgical engineering class who had an opportunity to participate in the Back in Black Hammer In co-curriculum and who had an exposure to redefined modules. For the most part, focus group discussions indicated that students enjoyed the creative opportunities allowed through the Hammer-In even though a number of the participants did not actually participate in the program. Most participants felt that the one of the strengths of the program was exposure to the concepts ahead of time and a reinforcement of major concepts through laboratory modification. Areas for improvement included suggestions for laboratory structure, some laboratory concepts were an unnecessary repeat of Met 231 and 330. Met 440 labs were similar to some of the MET 330 labs but were a good reinforcement with the exception that stress concentrations were difficult to see in a lab. The SEM lab and tensile testing labs were particularly helpful. Wait times for the Hammer-In can be long and the blacksmithing equipment should be doubled or tripled and that it would helpful to have one day a month set aside for women.

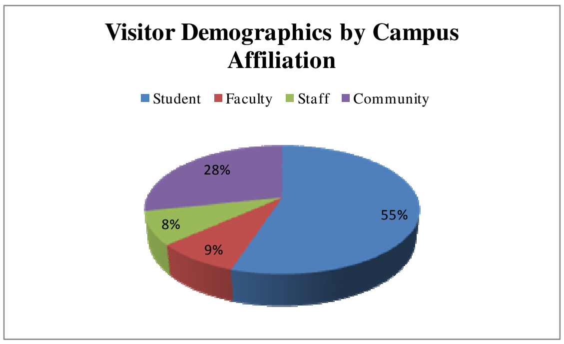
Outreach: In February, the Gallery sponsored a metals and blacksmithing art show and showcased some of the student's work. The Apex Gallery featured a Back in Black art show during February, 2009 which spanned Engineers Week. Visitors were given an opportunity to complete a short survey (appendix A) the assessed community impact, demographic information, and general perceptions. While visitors were not required to submit a survey, visitors who submitted a survey were eligible to receive one of two $30 gift certificates to a local popular restaurant. A total of 61 visitors submitted surveys. Visitor demographics are shown below in Figure 4 a-d.



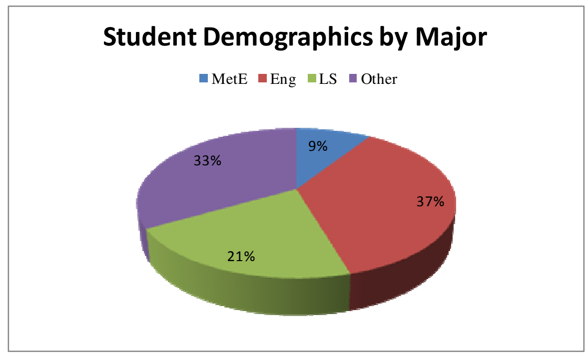
(a) Visitor Demographics by Gender



(b) Visitor Demographics by Race



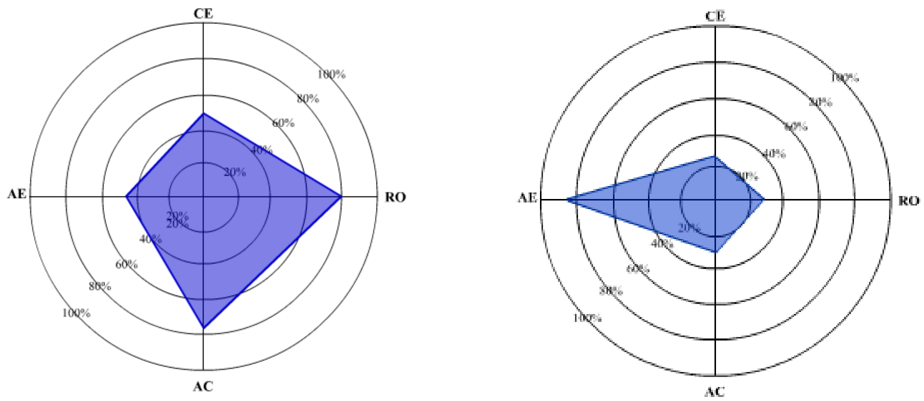
(c) Visitor Demographics by Campus Affiliation



(d) Student Demographics by Major

Figure 4. Visitor Demographics to APEX Gallery for Back in Black Exhibit

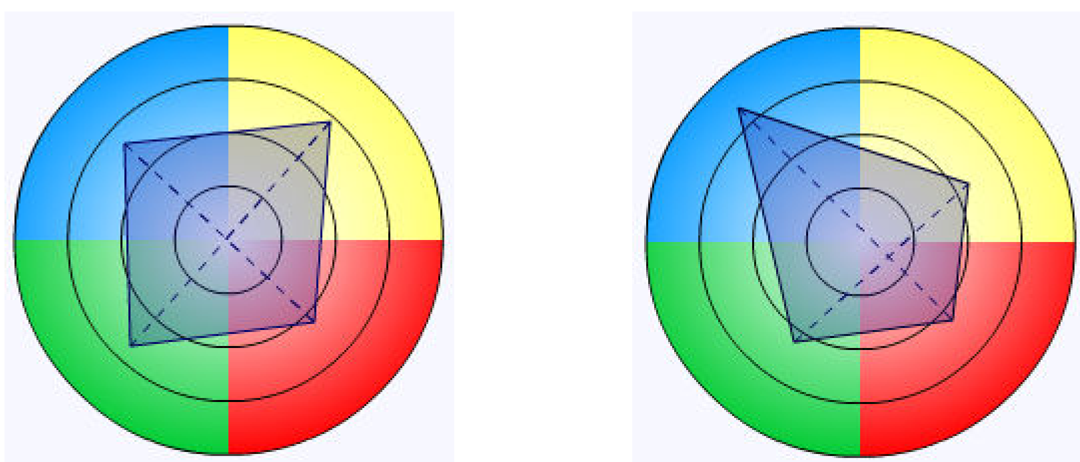
Hermann Brain Dominance Inventory: There is some research that suggests that a mismatch between a student's learning style and analytic traditional engineering curriculum may be a contributing factor to attrition in engineering programs[2]. A variety of measures of student typology exist (e.g.; Visual, Aural Reading, Kinesthetic Inventory[3], Myers-Briggs Type Indicator[4], Index of Learning Styles[5], Kolb[6], and Hermann Brain Dominance Indicator[7]). While first year engineering students tend to have more diverse learning styles and modes of intellectual inquiry (Figure 5.a. shows SDSM&T baseline for 2005), the traditional engineering curriculum often tends to support students with a stronger preference for active experimentation. As a result, students with a stronger preference for reflective observation tend to be discouraged from continuing in a traditional engineering curriculum, which tends to focus on active experimentation and concrete experience. Because of this mismatch, students that are otherwise capable tend to leave. Since student typology does not change, the result is an average learning preference curve that is more highly skewed towards active experimentation for matriculating students (Figure 5.b).



(a) For Engineering Freshmen (b) For Graduating Seniors

Figure 5. Average Learning Preference Curves for Engineering Freshmen and Graduating Seniors

Since the Herrmann Brain Dominance Inventory (HBDI) is a more reliable instrument than the Kolb, the campus is transitioning from Kolb to HBDI. Although the epistemological assumptions are different between the Kolb LSI and the HBDI, they both represent student typologies and there is some evidence that the two may be highly correlated. Under the current hypothesis Figure 6.a for the HBDI would reflect the average thinking preference curve for the same first year engineering students as shown in Figure 5a for the Kolb. Upper division students in MET 440 were offered an opportunity to complete the Herrmann Brain Dominance indicator in late April of 2008. Because of a snow storm and subsequent campus closure, only 6 students completed the inventory. The average thinking preference curve is shown in Figure 6.b below.



(a) For Engineering Freshman (b) For Seniors in MET 440

Figure 6. HBDI Profile for First Year Students and Senior Level MET Students

If the program successfully attracts and retains more diverse learners, one should see gradual shifts in the average learning preference curve for matriculating students. Specifically, by integrating form and function through the Back in Black program, the potential exists to provide a learning environment for students who are more conceptual in their thinking. That is, the average learning preference curve in Figure 6.b would more closely align with the average learning preference curve in Figure 6.a. At this point, additional data would have to be obtained before more definitive conclusions or recommendations could be made.

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