AC 2011-837: IMPLEMENTATION AND ASSESSMENT OF A CAPSTONE COURSE DESIGNED TO ACHIEVE PROGRAM LEARNING OBJECTIVES

Mohamed E. El-Sayed, Kettering University

Dr. Mohamed El-Sayed is a professor of Mechanical engineering and director of the Hybrid Electric Vehicle Integration and Durability Laboratory, Kettering University. He is the current Editor-in-Chief of the SAE journal of Materials and Manufacturing. Dr. El-Sayed has over thirty years of teaching experience in the area of design, design simulation, design optimization, and automotive design. Dr. El-Sayed has over twenty years of Automotive Design, Development, and Validation experience. Dr. El-Sayed was the lead engineer on the design optimization and quality/Durability/Reliability Integration of several General Motors Vehicles, Platforms, and Architectures. He was a Quality, Reliability and Durability (QRD) Performance Integration Team Leader and Subject Matter Expert at General Motors Car group, Truck Group, and Advanced Vehicle engineering for over ten years. Dr. El-Sayed has several awards from GM related to vehicle development and validation. Dr. El-sayed has also worked as the chief engineer for Joalto Design developing advanced automotive components and safety subsystems. Dr. El-Sayed has advised several Ph.D., Master and over a hundred automotive related theses. He has several patents, and published over seventy research papers.

Jacqueline A. El-Sayed, Kettering University

Dr Jacqueline El-Sayed is a professor of Mechanical Engineering at Kettering University and the Richard L. Terrel Professor of Excellence in Teaching. She is the founding chairperson of the Planning and Assessment Council appointed by the provost and president. This university wide, shared governance council facilitates the strategic planning and assessment for the campus. In addition she is a commissioner for the State of Michigan in the area of commercial vehicle safety. She is married and has three children.

Timothy M. Cameron, Miami University

IMPLEMENTATION AND ASSESSMENT OF A CAPSTONE COURSE DESIGNED TO ACHIEVE PROGRAM LEARNING OBJECTIVES

Abstract

The view of a capstone course or experience depends on how the education process as whole is viewed. When an educational program is designed, the learning outcomes can be viewed as the desired attributes or abilities of the learner at the end of the program. The program itself becomes the process through which these attributes are achieved. Each designed course in the program is a sub-process with its learning outcomes incrementally contributing to the final program learning outcomes. Each course or sub-process is designed for the learner development towards the final goal state and validated based on the course set criteria or outcomes.

Capstone courses are usually the last phase for development and validation of the program itself. For this reason capstone courses, concerning the validation aspect, should share the final validation criteria with the program. As for the development aspect all the efforts during the course should be driven to close the gap between the learner state entering the course and goal state at the end of the course as well as the program. In this paper, the implementation and assessment of this view of a capstone course is studied.

In this study, the course learning objectives are aligned with the Program Educational Objectives and a set of Performance Indicator is developed. To measure the gaps for each team of students, in the capstone course, assessment for each Performance Indicator is conducted at the beginning of the course. These assessments are based on established performance targets and are used as indicators of the gaps to be closed for each team. These gaps are used to guide and monitor the activities of each team until the end of the course. At the end of the course, using the same targets, assessment of each team performance is again conducted to measure the extent of the gap closure, as well as course and program assessment. To demonstrate the implementation process, some assessment data and results are discussed.

Introduction

The First National Survey of Senior Seminars and Capstone Courses conducted in 1999 suggested that these courses place the highest priority on culminating learning in the academic major, and more than 70% require a major project or presentation.[1] While a capstone course was originally viewed as the "finishing touch" to provide students with the needed information or skills before graduation[2,3], another view was developed considering a capstone course as an opportunity for students to demonstrate that they have achieved the goals for learning established by their educational institution and major department.[4] Through careful examination of both views it is clear that the original view may lead to focusing on knowledge exchange and skills development with no performance measures and the second view may cause no extra meaningful knowledge and skills to be developed in the course.[5]

A recently developed view of the capstone course that allows for the natural integration with the educational program was presented[5], in this view, the program educational outcomes are

considered as the desired attributes or abilities of the learner at the end of the program. The program itself is the process through which these attributes are achieved. Each designed course in the program is a sub-process with its learning outcomes incrementally contributing to the final program educational outcomes. Each course or sub-process is designed for the learner development towards the final goal state and validation is conducted based on the course set criteria or outcomes. While the development is continuous the validation is distributed along the course duration or increments. In this view, capstone courses are usually the last phase for development and validation of the program itself. For this reason capstone courses, concerning the validation aspect, should share the final validation criteria with the program for its assessment. [6-9]As for the development aspect all the efforts during the course should be driven to close the gap between the learner state entering the course and goal state at the end of the course as well as the program.[5]

In the following, the integration of a capstone course with a program will be discussed. The integration of the capstone course with the program was implemented by sharing the same learning objectives and outcomes.

Capstone Course Implementation

The view of a capstone discussed in refernce[5] was implemented in an educational program having following five Program Educational Objectives (PEO's):

PEO 1: Showing leadership in contributing to the success of their teams
PEO 2: Work collaboratively to synthesize information and formulate, analyze and solve problems with creative thinking and effective communication.
PEO 3: Make professional decisions with an understanding of their global, economic, environmental, political and societal implications.
PEO 4: Apply modern tools and methodologies for problem solving, decision making and design.
PEO 5: Commit to professional and ethical practices, continuous improvement and life-long learning.

In addition to meeting its own discipline specific outcomes, the program must meet the set of ABET Student Outcomes shown in Table 1. Simple mapping of the ABET Student Outcomes and Program Educational Objectives is shown in table 2. From table 2, it is clear that several outcomes contribute to an educational objective and several educational objectives could be related to one student outcome.

Guided by the program's vision during the course design and development phases the Program Educational Objectives and ABET Student Outcomes are used as the Course Learning Objectives and Outcomes. All course activities are designed to achieve the program education objectives and student outcomes based on the needs of each student team in addition to finishing the capstone project.

Table 1 - ABET Program Outcomes

A. An ability to apply knowledge of mathematics, science and engineering.
B. An ability to design and conduct experiments, as well as to analyze and interpret data.
C. An ability to design a system, component, or process to meet desired needs.
D. An ability to function on multi-disciplinary teams.
E. An ability to identify, formulate and solve engineering problems.
F. An understanding of professional and ethical responsibility.
G. An ability to communicate effectively.
H. The broad education necessary to understand the impact of engineering solutions in a global and societal context.
I. A recognition of the need for, and an ability to engage in life-long learning.
J. A knowledge of contemporary issues.
K. An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Table 2 - Mapping between ABET Student Outcomes (SO) and Program Educational Objectives

SO / PEO	PEO 1	PEO 2	PEO 3	PEO 4	PEO 5
A		X		X	
B		X		X	
C		X		X	
D	X	X			
E		X		X	
F			X		X
G	X	X			
H			X		X
I					X
J			X		X
K			X	X	

During implementation, to achieve the Program Education Objectives, the main drive of the capstone integration is: to close the gap between the program's goal and the learners' state at the entry point to the course. This gap analysis is formative assessment[10] starting at the first week of the course. The Student Outcomes are assessed using multiple Performance Indicators (PI's). For simplicity, in this paper only one PI is illustrated for each Student Outcome and linked to one Program Education Objective. These are listed in Table 3-6. To assess each PI, students are

instructed to develop a plan for executing their selected project and explain the contribution of each member. Team work is the key PI linked to PEO 1. Students are asked to collaboratively analyze and formulate the design problem for PI's linked to PEO 2, but creative thinking is the PI provided as the example below. In addition, they elaborate on how and why they arrived at their decisions and the global, economic, and environmental impacts of these decisions for the PI's linked to PEO 3. As for the PI's for PEO 4 and PEO 5, students are instructed to address their design approach, the tools, processes, resources, knowledge, and skills needed for project execution in addition to accounting for all ethical considerations.

The initial reports and presentations for all the teams are assessed during the second week based on pre established criteria and rubrics. These set of criteria and rubrics are developed for each Performance Indicators that relates to the one Student Outcomes and linked to one Program Education Objectives. Rodgers[11] provides examples of the analytic rubrics used. The gap for each team is then determined and planned activities for each team are designed and monitored to the end of the term.

At the end of the course, using the same targets, criteria, and rubrics the final assessment for each Performance Indicators is performed for each team. These assessments are performed using direct assessment methods, based on the final project report and presentation of each team. The direct assessment methods used include portfolios, performance appraisals and behavioral observations and the assessment is standardized through the use of the rubrics.

For course/program assessment and continuous improvement the average gain in gap closure for each linked PEO is estimated. Continuous improvement can be gained on both the course and program levels. In the following the course assessments methodology and results are discussed.

Capstone Course Assessment Methodology and Results

To achieve the course learning objectives a Performance Index relating to each Performance Indicators is developed for every team in the class. These Performance Indices are based on different targets for each performance indicator which relates to the educational objectives at the time of graduation. These performance indices are developed using the following equation:

$$\text{Performance Index (PI)} = [1 - (\text{Target Level} - \text{Assessed Level}) / \text{Target Level}] \times 100 \qquad (1)$$

Equation 1 is used to develop the course initial and final Performance Indices for every team in the class to assess the performance level of each Performance Indicator.

The course Initial Performance Indices (IPI's) are developed at the beginning of the class. These indices are indicators for the gap to be closed by each team. These gaps are used to guide and monitor the activities to the end of the course in order to customize the learning for each team. The initial class assessment and performance index (IPI) for selected performance indicators are shown in Table 3 and Table 4 respectively. The final class assessment and

performance index (FPI) for selected performance indicators are shown in Table 5 and Table 6 respectively.

For assessment and continuous improvement of the course itself the average initial performance index (IPI) and the average final performance index (FPI) are calculated for each Performance Indicator as shown in Table 4 and Table 6. The course average initial performance index (IPI) and the average final performance index (FPI), are used in Figure 1 to graphically demonstrate the overall class gaps and achievements for each performance indicator.

Table 3 - Capstone Initial Assessment Data

Perceived level is based on the following scale: 1 Low 2 3 Medium 4 5 High	Team 1	Team 2	Team 3	Team 4	Team 5	Class Ave.
Capstone students demonstrate leadership in developing a teamwork plan. (Target Level = 4)	3.8	3.6	3.8	3.8	3.7	3.7
Capstone students demonstrate creative thinking in design. (Target Level = 4.5)	4.1	3.7	4.0	4.2	4.0	4.0
Capstone students understand their professional decision impacts. (Target Level = 4)	3.6	3.5	3.7	3.5	3.7	3.6
Capstone students apply modern tools for problem solving. (Target Level = 4.5)	4.1	4.0	4.1	4.2	4.1	4.1
Capstone students apply the code of ethics to their project. (Target Level = 4)	3.5	3.4	3.5	3.5	3.5	3.5

Table 4 - Capstone Initial Performance Index (IPI)

Perceived Initial Performance Index	Team 1	Team 2	Team 3	Team 4	Team 5	Class Ave
Capstone students demonstrate leadership in developing a teamwork plan. (Target Level = 4)	95	90	95	95	93	93
Capstone students demonstrate creative thinking in design. (Target Level = 4.5)	90	80	88	93	88	88
Capstone students understand their professional decision impacts. (Target Level = 4)	90	88	93	88	93	90
Capstone students apply modern tools for problem solving. (Target Level = 4.5)	92	90	92	94	92	92
Capstone students apply the code of ethics to their project. (Target Level = 4)	88	85	88	88	88	88

Table 5 - Capstone Final Assessment Data

Perceived level is based on the following scale: 1 2 3 4 5 Low Medium High	Team 1	Team 2	Team 3	Team 4	Team 5	Class Ave.
Capstone students demonstrate leadership in developing a teamwork plan. (Target Level = 4)	3.9	3.7	3.9	3.9	3.8	3.8
Capstone students demonstrate creative thinking in design. (Target Level = 4.5)	4.4	4.0	4.3	4.4	4.4	4.3
Capstone students understand their professional decision impacts. (Target Level = 4)	3.9	3.7	3.9	3.8	3.9	3.8
Capstone students apply modern tools for problem solving. (Target Level = 4.5)	4.3	4.1	4.2	4.4	4.2	4.2
Capstone students apply the code of ethics to their project. (Target Level = 4)	3.8	3.7	3.8	3.8	3.8	3.8

Table 6 – Capstone Final Performance Index (FPI)

Perceived Final Performance Index	Team 1	Team 2	Team 3	Team 4	Team 5	Class Ave.
Capstone students demonstrate leadership in developing a teamwork plan. (Target Level = 4)	98	93	98	98	95	95
Capstone students demonstrate creative thinking in design. (Target Level = 4.5)	98	89	96	98	98	96
Capstone students understand their professional decision impacts. (Target Level = 4)	98	93	98	95	98	95
Capstone students apply modern tools for problem solving. (Target Level = 4.5)	96	92	94	98	94	94
Capstone students apply the code of ethics to their project. (Target Level = 4)	95	93	95	95	95	95

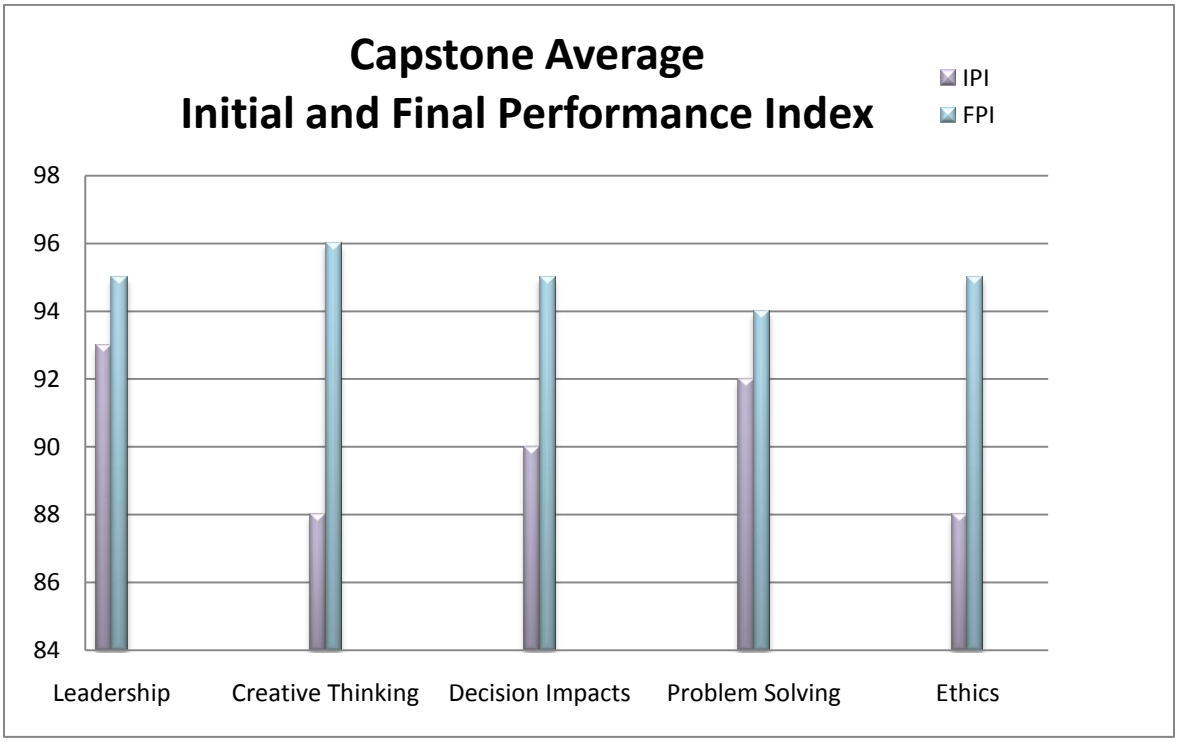

Figure 1 – Capstone Initial and Final Performance Indices

As shown in Figure 1, by identifying the gap the target areas for improvement and the effort needed can be focused. For the specific course presented in this work it is clear that some improvement in each of the PI's was achieved during the course. From the figure it is also clear that the highest achievements were in the areas of creative thinking and ethical practices. The least improvements were in the areas of leadership and problem solving.

To assess the course and program outcomes the mapping of Table 2 was used with the course final program assessment of Table 6 to estimate the performance index for each ABET Student outcome as shown in Figure 2. From figure 2, it is clear that the estimated performance index for each ABET Student outcome is about 95% satisfaction level.

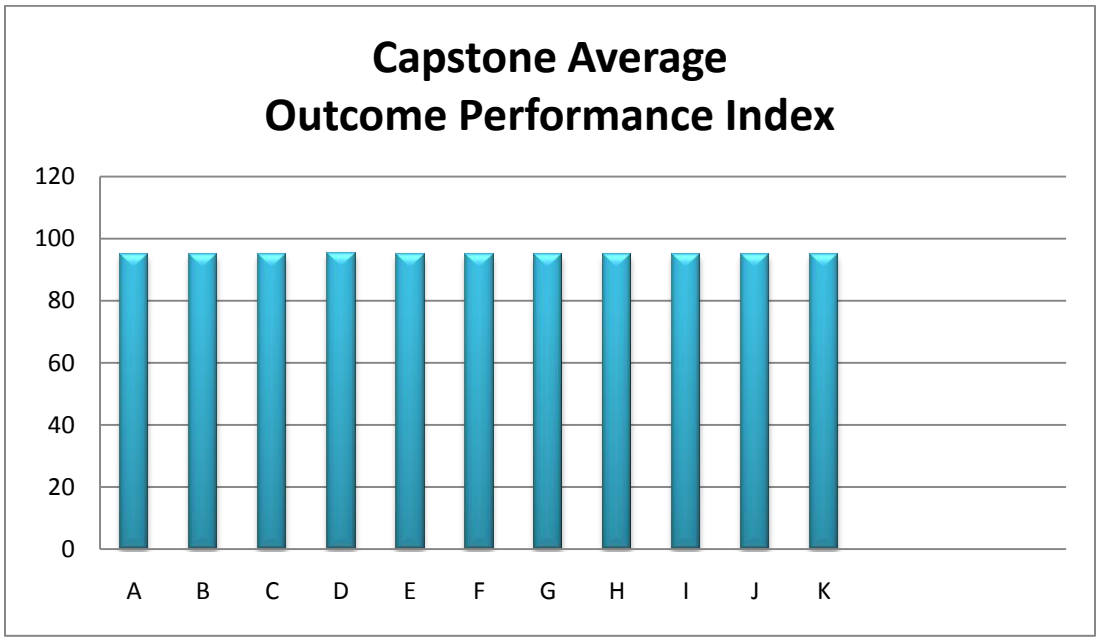

Figure 2 – Capstone outcome Performance Indices

To validate the direct assessment of the Performance Indicators a survey was conducted for graduating seniors in the program. Surveys are considered indirect assessment methods and should be used in conjunction with direct assessment methods. Alumni survey was not possible since the implementation has not been in effect for three years yet. The comparison between the final assessment and the survey results is shown in figure 3.

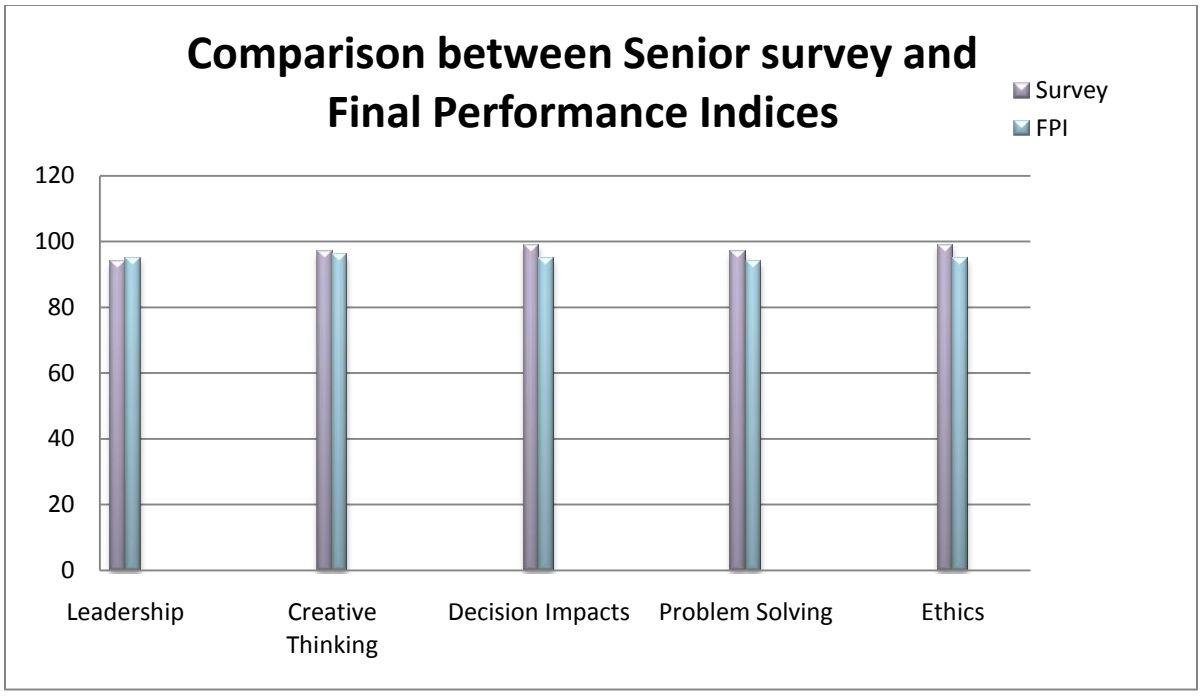

Figure 3 – Survey vs. Final Performance Indices

As shown in Figure 3 the graduating seniors' perceived performance is slightly higher than the direct assessment results except for leadership. This difference is due to the definition of leadership. For students it usually mean being the "Boss" while in direct assessment of the course it is defined as service leadership in contributing to the team success.

Conclusion

By sharing the Program Education Objectives and Student Outcomes a capstone course could have a better integration with the educational program. This integration can be achieved since the capstone is the final validation of the program. Through successful design, development, and implementation, a capstone course could play an active role in achieving the program educational objectives and student outcomes. The key to successful course integration is to understand the overall program assessment process.

During the course design and development the course the structure should be flexible to include a variety of activities in addition to the main design projects. These activities should be designed into an action plan to address the different gaps of learning for each project team. Also, due to rapid changes in professional practices in terms of knowledge, processes, required skills, and tools these activities should be updated over time to adjust for the changes in the professional environment.

The development of the accurate set of performance gaps for each student team is the key for successful implementation of an integrated capstone course. It is essential to standardize the assessment through rubrics. The instructor should observe the ongoing team performance in order to mentor the students and increase student success. By doing this, the capstone becomes a more meaningful course for the students' development.

An integrated capstone course can also provide a meaningful assessment and evaluation for the program continuous improvement and accreditation. By measuring the achievements for the performance indicators, the capstone course assessment can be viewed as a significant indicator for the program assessment, as well. It is a best practice that the set of performance indicators and rubrics used for identifying the gaps and assessing the course should be developed in collaboration with the program faculty and stakeholders.

References

1. Henscheid, J. M., "Professing the disciplines: An analysis of senior seminars and capstone courses," *National Resource Center for the First Year Experience and Students in Transition*, Monograph No. 30, Columbia, SC: University of South Carolina, 2000.

2. Kerka, S., "Capstone experiences in career and technical education," *Practice Application Brief No16, Clearing house on Adult, Career, and Vocational Education,* 2001.

3. Clear, T., Goldweber, M., Young, F., Leidig, P & Scott, K., "Resources for instructors of capstone courses in computing," *Working Group Report ITiCSE 2001,* SIGCSE Bulletin 33, 4, 93-113, 2001.

4. Kemp, J. E. & Smellie, D. C., *Planning, producing, and using instructional media* (6th ed.). New York: Harper Collins, 1989.

5. El-Sayed, M. "Design and Integration of a Capstone Course to Achieve Program Outcomes" *Proceedings of American Society for Engineering Education Annual Conference, Pittsburgh, PA, June 2008.*

6. Beyerlein, S., Davis, D., Trevisan, M., Thompson, P. & Harrison, K., "Assessment Framework for Capstone Design Course," *Proceedings of American Society for Engineering Education Annual Conference*, Chicago, IL, June 2005.

7. Pellegrino, J., Chudowsky, N., & Glaser, R., *Knowing what students know: The science and design of educational assessment*. Washington, DC: National Academy Press, 2001.

8. Johnson, R. *The capstone course: A synergistic tool for pedagogical and assessment goals in higher education*. Paper presented at the 10th AAHE Conference on Assessment and Quality, Boston, MA, June 1995.

9. Nichols, J.A. "Capstone courses: A model for assessing quality of student learning. In T. W. Banta & C. L. Anderson, eds. *Proceedings of the Fourth International Conference on Assessing Quality in Higher Education*, Netherlands: University of Twente, 1992.

10. Terenzini, P. T. "Assessment with Open Eyes: Pitfalls in Studying Student Outcomes." *Journal of Higher Education* (November/December, 1989) 60: 644-664.

11. Rodgers, G. *ABET IDEAL Scholar Manual*, Baltimore, MD, August 2009.