



Title	The Systematic Development of Rubrics in Assessing Engineering Learning Outcomes
Author(s)	Zou, XT; Ko, E; Li, C; Zhou, C
Citation	The 1st I E E E International Conference on Teaching, Assessment and Learning for Engineering (TALE 2012), Hong Kong, China, 20-23 August 2012. In the Proceedings of I E E E International Conference on Teaching, Assessment and Learning for Engineering, 2012, p. T1A-1 - T1A-5
Issued Date	2012
URL	http://hdl.handle.net/10722/216300
Rights	I E E E International Conference on Teaching, Assessment and Learning for Engineering. Copyright © I E E E.

The Systematic Development of Rubrics in Assessing Engineering Learning Outcomes

Tracy Chow, Edmond Ko, Cindy Li, and Catherine Zhou

Center for Engineering Education Innovation
The Hong Kong University of Science and Technology
Hong Kong SAR
egtracy@ust.hk

Abstract—Assessing student learning outcomes becomes more critical than ever to all universities in Hong Kong as the higher education system is migrating from the current three-year undergraduate curriculum to the four-year curriculum in the fall of 2012. This paper introduces an assessment plan developed in the School of Engineering at The Hong Kong University of Science and Technology to gather evidence on student learning outcomes through both internal and external stakeholders over a complete cycle. A number of surveys for different stakeholders are purposefully aligned to allow comparison between the two cohorts of students as well as among students, faculty, and employers. Assessment rubrics are systematically developed and embedded in all surveys and the assessment of capstone experience to facilitate a meaningful interpretation of results.

Index Terms—assessment; engineering; learning outcomes; rubrics

I. INTRODUCTION

Assessment of student learning outcomes is a critical element in the quality assurance of higher education in general, and engineering education in particular. As all the universities in Hong Kong will migrate from the current three-year undergraduate curriculum to the four-year curriculum in the fall of 2012 as part of the education reform, it is important for academic institutions to put in place a well-designed assessment plan to evaluate the effectiveness of the new curriculum based on reliable and credible evidence.

All engineering degree programs in Hong Kong are subject to the accreditation by the Hong Kong Institution of Engineers (HKIE), a statutory professional body for Hong Kong engineers. The attributes of engineering graduates specified by HKIE follow the same criteria of the Washington Accord, enabling graduates from Hong Kong to be recognized by signatory members worldwide [1]. The School of Engineering (SENG) at The Hong Kong University of Science and Technology (HKUST), in adherence to these graduate attributes, specified twelve intended student learning outcomes (hereafter referred to as SENG-ILOs, details shown in Appendix I). The SENG-ILOs are also aligned with the graduate attributes outlined by HKUST in the form of ABCLIVE (i.e., Academic excellence, Broad-based education, Competencies and capacity building, Leadership and teamwork, International outlook, Vision and an orientation to the future, and Ethical standards and compassion).

The assessment plan developed in SENG at HKUST aims to gather credible evidence on student learning outcomes through both internal and external stakeholders over a four-year time period. The learning outcomes are consistent with the desirable attributes of engineering graduates, which are specified in the Professional Accreditation Handbook [1], in line with the accreditation guidelines established by ABET, Inc. [2]. In this plan, surveys for different stakeholders are purposefully aligned to allow comparison between two cohorts of students as well as among students, faculty, and employers. Assessment rubrics are designed and embedded in all surveys and the assessment of capstone experience to facilitate a systematic and meaningful interpretation of assessment results.

II. OVERVIEW OF THE ASSESSMENT PLAN

The assessment plan, as shown in Fig. 1, covers the time period from students' entrance to HKUST in 2012/13 to their graduation. Students, faculty, and employers are involved in the plan to provide a comprehensive view on students' competency. A variety of methodologies, including questionnaires, interviews and focus groups, will be utilized. The plan enables two levels of comparison: (1) between the three-year cohort and the four-year cohort starting from the fall of 2012, and (2) between the inputs by students, faculty, and employers. Comparison of the assessment results between the two cohorts will provide evidence for the impact of the new four-year curriculum on student learning. Comparison among different stakeholders will reveal discrepancies in expectation and actual performance of students as well as concerns in curriculum design. The major components of the plan include the following:

- *Employer survey*: Employers in various sectors will be invited to provide their expectation of and feedback on the competency of HKUST graduates regarding SENG-ILOs. The employer survey will be conducted in 2012/13 and 2016/17;
- *Student entrance and exit surveys*: These two surveys serve as pre- and post- tests to assess students' competency before and after the engineering education processes. An exit survey with graduates of 2011/12 has been launched and the results will serve as baseline for future comparison. The entrance survey will be administered to entering students in 2012/13 of both

three-year and four-year cohorts. In 2015/16 and 2016/17, exit surveys will be administered to these two cohorts of students;

- *Faculty survey*: Engineering faculty will be invited to provide their opinions on different attributes of the graduates. A faculty survey has been launched in 2011/12 and another one will be conducted in 2016/17;
- *Assessment of capstone experience*: Capstone experience gives students the opportunities to solve real-world problems by integrating knowledge and skills acquired over the undergraduate years. Assessment of capstone experience involves the evaluation of students' written reports, oral presentation, and teamwork. The assessors include supervisors and examiners as well as students conducting self and peer evaluation.

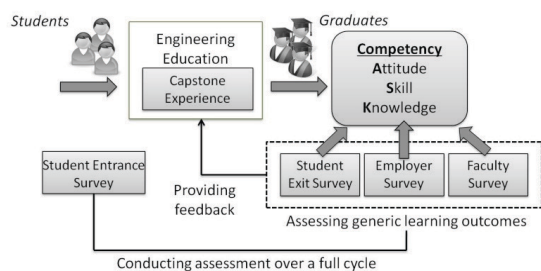


Figure 1. An overview of the assessment plan.

One distinguishing feature of this plan is that the questionnaire items in all four surveys are aligned to allow a systematic comparison among inputs from students, faculty, and employers. Particularly, assessment rubrics are embedded in all surveys to minimize ambiguity and uncertainty in interpreting the responses, which ensures that the two levels of comparison highlighted above are possible and meaningful.

III. RUBRICS IN THE ASSESSMENT PLAN

Rubrics are an assessment instrument that describes multiple levels of performance on several dimensions of a task or an item. It is particularly useful for assessing authentic and complex student work [3]. Provided that most SENG-ILOs are related to competencies that involve multiple dimensions and are often interpreted differently in different contexts, rubrics are considered particularly helpful.

A. Rubrics in the Employer Survey

The employer survey specifies three levels of performance on a number of dimensions for each of the SENG-ILOs in the form of a “mini-rubric” along the scale. In this design, the descriptions provided for each option reduced the ambiguity inherited in conventional questionnaires using a five-point Likert scale. An example about “lifelong learning” is shown in Fig. 2 to illustrate the format.

Lifelong learning, framed as “an ability to recognize the need for and to engage in lifelong learning” [1], [4] is one of the most desirable attributes of engineering graduates. The

major dimensions describing lifelong learning were identified through a literature review and contain elements such as planning and being committed to learning associated with the work environment [5], being able to go beyond the job duties [5], finding relevant sources of information about a specified topic [6], and identifying one’s learning style and describing the strength and weakness [6]. The rubric on lifelong learning developed by the Association of American Colleges and Universities (AAC&U) covers curiosity, initiative, independence, transfer, and reflection [7]. Based on an analysis of the above, three dimensions were selected and summarized as follows:

- Explore a topic and find relevant information (curiosity);
- Pursue additional knowledge beyond job duties (initiative and independence);
- Review prior learning experience, revealing clarified meaning, or indicating broader perspective about education or life (transfer and reflection).

For each of the above dimensions, three levels of performance were specified as follows:

- *Exemplary* (4–5): The graduate performs excellently at his/her own initiatives and is able to think critically about the processes/ outcomes;
- *Average* (3): The graduate performs well under guidelines/ supervision but lacks a critical perspective;
- *Needs work* (1–2): The graduate does not perform to a standard even under guidelines/ supervision.

Following this process, a mini rubric could be embedded in questions about lifelong learning. The employer survey addresses all twelve SENG-ILOs, with each framed in a similar design of rubrics as shown in Fig. 2. This resulted in a comprehensive questionnaire with each of the twelve SENG-ILOs represented by a number of dimensions and each dimension further explained through three levels of descriptors (i.e., “exemplary”, “competent” and “needs work”).

To solicit expert advice, the full questionnaire was shown to members in the Outcome-based Education (OBE) Steering Group of HKUST as well as representatives in each department within SENG. The feedback was positive regarding the questionnaire design. The representatives from different departments provided input to the questionnaire and also nominated employers to follow up in the pilot study.

A pilot study has launched and feedback through follow-up interviews has been collected from two organizations, one public transportation company and one construction company. The respondents commented that the questionnaire was very comprehensive, covering most essential attributes of an engineering graduate, and also clear and easy to understand. The descriptors defining the different levels of performance were also found useful for respondents to choose the option that reflected the actual level of the graduate.

An ability to recognize the need for, and to engage in lifelong learning						
h-1 Explore a topic and find relevant information						
<i>Expectation</i>	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> n/a
<i>Performance</i>	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> n/a
	Explore a topic and identify exiting information at a superficial level		Explore a topic and search for relevant information with some depth		Explore a topic and search for relevant information with depth; Show rich interest in the topic	
h-2 Pursue additional knowledge beyond job duties						
<i>Expectation</i>	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> n/a
<i>Performance</i>	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> n/a
	Show little interest in pursuing additional knowledge beyond job duties		Seek opportunities to expand knowledge, skills and abilities beyond job duties under guidance		Actively seek opportunities to expand knowledge, skills and abilities beyond job duties	
h-3 Review prior learning experience, revealing clarified meaning or indicating broader perspective about education or life						
<i>Expectation</i>	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> n/a
<i>Performance</i>	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5	<input type="checkbox"/> n/a
	Recall prior learning experience and repeat the same pattern of learning		Review prior learning experience to identify lessons learned; Make necessary changes to improve future performance		Review prior learning experience critically to obtain lessons learned; Make necessary changes to improve learning processes	

Figure 2. An example of the item design in the employer survey: A mini-rubric on lifelong learning.

B. Rubrics in the Assessment of Capstone Experience

The criteria established by HKIE [1] require engineering students to apply knowledge and skills to solve real-world engineering problems. Capstone design courses offer this experience which makes them essential in the undergraduate curriculum. Within SENG, a survey was conducted in the six departments to examine the current practice through document review and semi-structured interviews with a faculty coordinator in each department. The results showed that all the design-based capstone projects were completed in teams of three or four. A different track involved individual research-based projects (taking up about 10% of all the projects) that were only offered to students with excellent academic results. The common components for capstone project assessment were progress reports, final reports, oral presentations, and posters (optional in three departments). Some of these components were assessed by the project supervisor and one or two examiners assigned by the department. In addition, students were asked to submit a peer evaluation form at the end of the project to indicate each teammate's contribution to the project.

The introduction of rubrics in the capstone experience assessment mainly aims to ensure consistency between evaluations by different raters. It also serves to inform students clearly of what is expected. One rubric that could be shared across all SENG departments is the one on teamwork. The teamwork rubric ([8], refer to Appendix II) was built upon five essential elements for effective teams based on Lencioni's framework [9], which covered trust building, conflict resolution, commitment, accountability, and attention to results. The rubric specified three levels of performance on each of these elements, namely "exemplary", "competent", and "needs work". It can be used as a supplement to the current

peer evaluation to form a more objective and comprehensive assessment on teamwork components, instead of solely relying on self-reported individual contribution within the team.

The teamwork assessment rubric was validated through a pilot study in an undergraduate course adopting collaborative problem solving pedagogy, where 32 students worked in eight teams with four in each. At the end of the course, the instructor, five peer tutors (i.e., undergraduate students who demonstrated excellent performance in the same course in previous semester and were recruited as coaches for the student teams), and the students were required to use the rubric to evaluate team performance. A correlation analysis using Spearman's rho test showed that the scores given by peer tutors were highly correlated with those given by the instructor ($r = 0.900$, $p < 0.01$) and the students ($r = 0.850$, $p < 0.01$) [8]. The alignment of assessment scores shown in the pilot study established inter-rater reliability of the rubric.

IV. DISCUSSION AND CONCLUSION

Although the assessment plan is yet to be fully implemented, the pilot study of the employer survey and the in-house survey on assessing capstone experience have demonstrated the value of rubrics in the assessment of engineering learning outcomes. The use of rubrics enables a more objective and comprehensive evaluation on the competencies of graduates. The rubrics on lifelong learning and teamwork are introduced not simply because these are two critical attributes desired by employers and the society at large. The more important reason is that neither students nor assessors (for example, instructors and employers) can explain clearly what is required under these two broad concepts without the detailed descriptions provided. Rubrics reduce ambiguity and facilitate a better interpretation of data.

The development of rubrics involves a number of issues that need to be carefully considered. One is the determination of dimensions for each ILO. Some ILOs, such as problem solving, teamwork, and communication, are professional skills involving many dimensions and can be interpreted differently by different stakeholders. To determine the dimensions in the engineering context, a literature review and subsequent analysis should be conducted to categorize the existing elements and select the appropriate ones. Equally important is that the descriptors need to be carefully constructed to reflect performance at each level.

Validation of rubrics is another critical issue. A pilot is necessary to validate wording preferably with end users of the rubrics, and more importantly, to establish inter-rater reliability through examining consistency between different assessors [3]. Based on the promising results of the teamwork rubric from the pilot study, rubrics for assessing other competencies in capstone experience (e.g., reports and presentations) would be developed and validated through similar processes.

A practical concern with the assessment plan is how students, faculty, and employers use rubrics in practice. The rubrics should be shown to students at the early stage of the capstone experience so that they will be well informed of what is expected. Students and faculty also need to be briefed about how to use rubrics in assessment. A careful validation of the rubrics with assessors through pilot studies can also be useful.

REFERENCES

- [1] Hong Kong Institute of Engineers (HKIE), *Professional Accreditation Handbook (Engineering Degrees)*, Hong Kong: Hong Kong Institute of Engineers, 2011.
- [2] ABET, Inc.(2012). *Criteria for Accrediting Engineering Programs, 2012–2013* [Online]. Available: <http://www.abet.org/engineering-criteria-2012-2013>.
- [3] A. Jonsson and G. Svingby, "The use of scoring rubrics: Reliability, validity, and educational consequences," *Educ. Res. Rev.*, vol. 2, pp. 130–144, 2007.
- [4] International Engineering Alliance (IEA), *Graduate Attributes and Professional Competencies* [Online]. Available: <http://www.ieagrements.org/>.
- [5] J. D. Lang S. Cruse, F. D. McVey, and J. McMasters., "Industry expectation of new engineers: A survey to assist curriculum designers," *J. Eng. Educ.*, vol. 88, pp. 43–51, Jan. 1999.
- [6] R. M. Felder and R. Brent, "Designing and teaching courses to satisfy the ABET engineering criteria," *J. Eng. Educ.*, vol. 92, pp. 7–25, Jan. 2003.

- [7] T. Rhodes, *Assessing Outcomes and Improving Achievement: Tips and Tools for Using Rubrics*, Washington, DC: Association of American Colleges and Universities, 2010.
- [8] T. X. P. Zou et al., "Promoting multi-layered peer learning in a course on engineering grand challenges," presented at Int. Conf. Teaching and Learning in Higher Education, Seremban, Malaysia, 2012.
- [9] P. Lencioni, *The Five Dysfunctions of a Team: A Leadership Fable*, San Francisco: Jossey-Bass, 2002.

APPENDIX I

SENG Intended Learning Outcomes (SENG-ILOs)

- 1) An ability to apply knowledge of mathematics, science, and engineering appropriate to the degree discipline
- 2) An ability to design and conduct experiments, as well as to analyze and interpret data
- 3) 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
- 4) An ability to function on multi-disciplinary teams
- 5) An ability to identify, formulate, and solve engineering problems
- 6) An understanding of professional and ethical responsibility
- 7) An ability to communicate effectively
- 8) An ability to understand the impact of engineering solutions in a global and societal context, especially the importance of health, safety, and environmental considerations to both workers and the general public
- 9) An ability to recognize the need for, and to engage in lifelong learning
- 10) An ability to stay abreast of contemporary issues
- 11) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice appropriate to the degree discipline
- 12) An ability to use the computer/ IT tools relevant to the discipline along with an understanding of their processes

APPENDIX II Teamwork Assessment Rubric

Team		Assessor		Date	
------	--	----------	--	------	--

Category/ Criteria	Exemplary (5)	Competent (3)	Needs Work (1)	Score
Trust	Team members are genuinely open with one another. They always share their weaknesses and mistakes.	Team members are reasonably open with one another. They occasionally share their weaknesses and mistakes.	Team members are not open with one another. They rarely share their weaknesses and mistakes.	
Conflict	Team members actively embrace different ideas and commit to resolving conflicts as they arise. Team meetings are always lively and interesting.	Team members are willing to discuss different ideas and deal with conflicts occasionally. Team meetings are often lively and interesting.	Team members shy away from conflicts and are not willing to discuss different ideas. Team meetings lack energy.	
Commitment	Team members are very clear about the team's direction and priorities and totally committed to realizing the team's goals.	Team members can agree on the team's direction and priorities and commit to realizing the team's goals.	Team members have different ideas of what the team goals are and lack the commitment to move forward as a team.	
Accountability	Team members always put the team's interests ahead of individual interests and keep one another accountable.	Team members attempt to let one another know when individuals do not act in the best interest of the team.	Team members avoid keeping one another accountable for actions and behaviors that would hurt the team's progress.	
Results	Team members always stay focused on team goals, maintain a high level of motivation, and celebrate success along the way.	Team members stay reasonably focused on team goals and can make steady progress towards them.	Team members are easily distracted and lose sight of team goals, resulting in a loss of motivation or lack of progress.	

Things that the team did well:	Things that the team could have done better:

This assessment rubric is adopted from the model in: Patrick Lencioni (2002) *The Five Dysfunctions of a Team: A Leadership Fable*, San Francisco: Jossey-Bass.