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Rubrics for Engineering Education

Introduction

Rubrics are scoring or grading tool used to measure a students' performance and learning across a set of criteria and objectives. There is no unified set of rubrics because the scoring rubrics vary accordingly across different disciplines and courses. There are three components within rubrics namely (i) dimensions/criteria: the aspects of performance that will be assessed, (ii) descriptors: characteristics that are associated with each dimension, and (iii) scale/level of performance: a rating scale that defines students' level of mastery within each criterion. Figures 1 and 2 presented below show that the scales and dimensions of rubrics can exchange position.

Figure 1: Example of Rubrics (Accessed from Rogers, 2010)

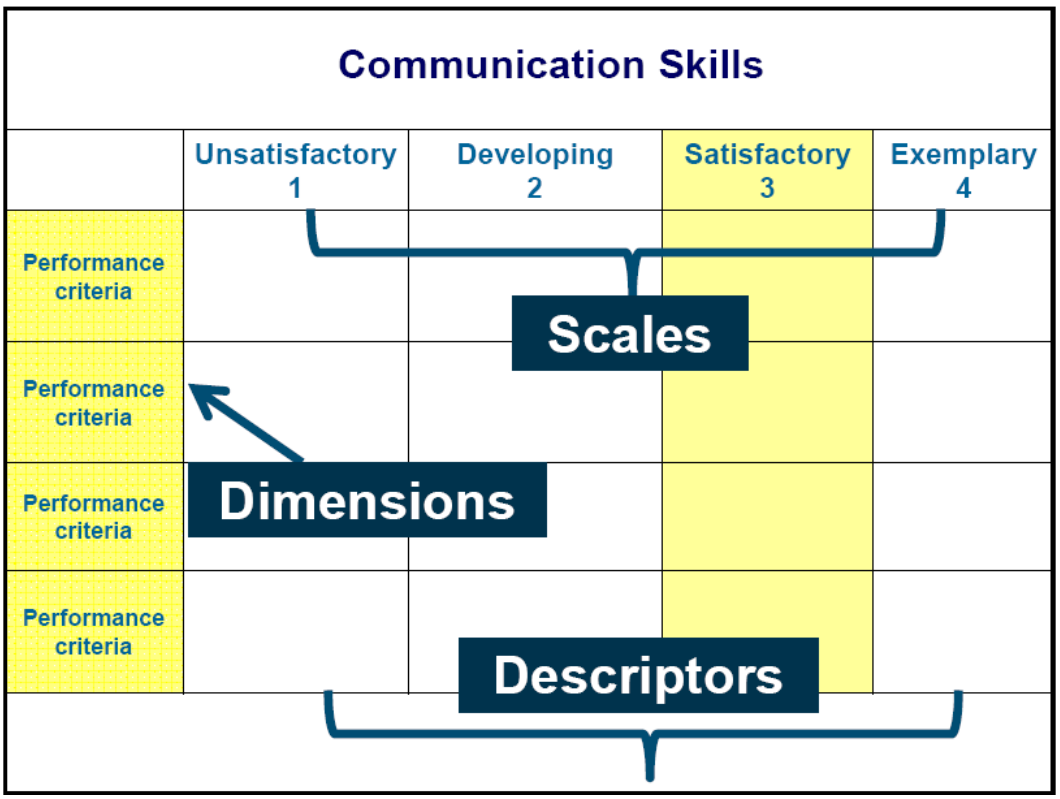
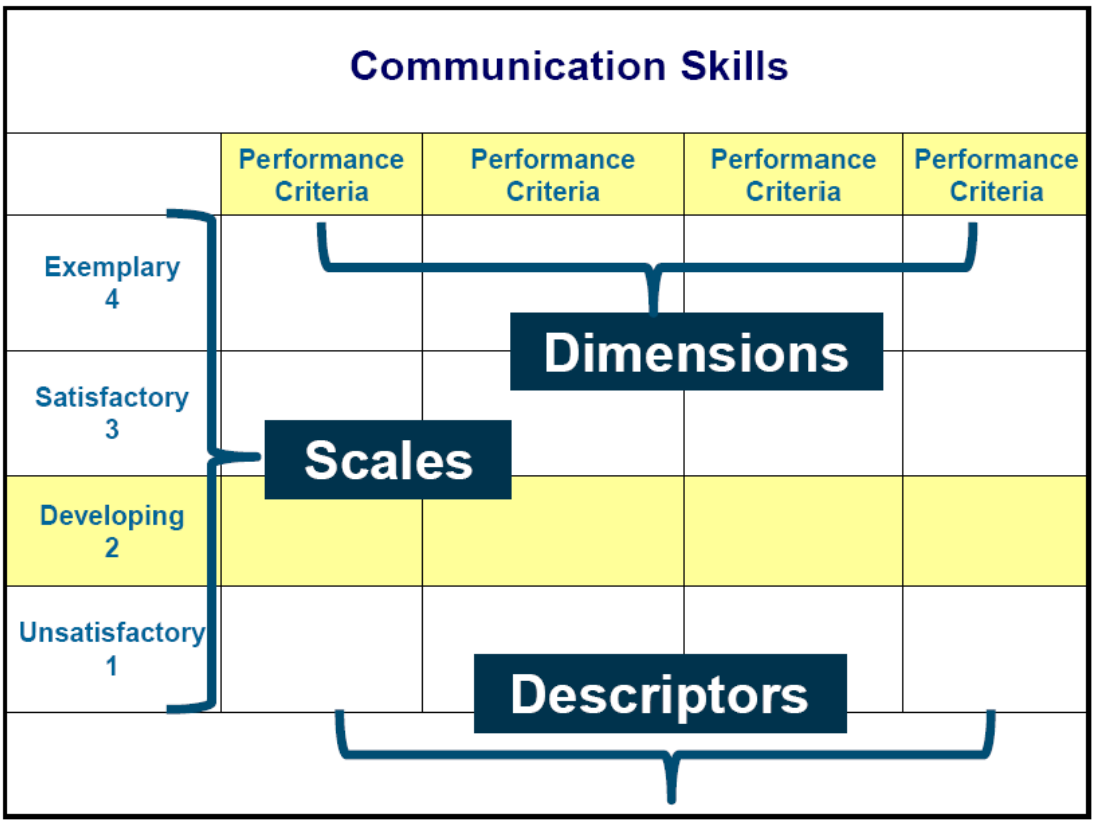


Figure 2: Example of Rubrics (Accessed from Rogers, 2010)



The use of rubrics aids teachers to assess students' work objectively and effectively. It can be used for both summative and formative purposes. Rubrics can (a) offer ways to define expectations, especially in dealing with processes or abstract concepts, (b) provide a common language to help teachers and students discuss about the expected learning, (c) increase reliability of the assessment when using multiple assessors, and (d) provide feedback to students on various forms of assessments. (Rogers, 2010)

References:

- Rogers, G. (2010). Developing rubrics. Retrieved from http://www.abet.org/uploadedFiles/Events/Webinars/Developing_Rubrics.pdf

Types of Rubrics

There are two types of rubrics, “holistic rubrics” and “analytic rubrics”.

Holistic rubrics do not list separate levels of performance for each criterion. Assigning a level of performance is done by assessing performance across multiple criteria as a whole.

When using holistic rubrics, the assessor makes judgment by forming an overall impression of the performance and matching the performance to the descriptions that is most suited along the scale. Each category on the scale describes performance on several performance criteria.

Figure 1: Example of Holistic Rubrics (Accessed from Rogers, 2010)

Work Effectively in Teams

Unsatisfactory 1	Developing 2	Satisfactory 3	Exemplary 4
➢Does not collect any information that relates to the topic. ➢Does not perform any duties of assigned team role. ➢Always relies on others to do the work. ➢Is always talking--never allows anyone else to speak.	➢Collects very little information--some relates to the topic. ➢Performs very little of assigned duties. ➢Rarely does the assigned work--often needs reminding. ➢Usually doing most of the talking--rarely allows others to speak.	➢Collects some basic information--most relates to the topic. ➢Performs nearly all assigned duties. ➢Usually does the assigned work--rarely needs reminding. ➢Listens, but sometimes talks too much.	➢Collects a great deal of information--all relates to the topic. ➢Performs all duties of assigned team role. ➢Always does the assigned work without having to be reminded. ➢Listens and encourages others to participate.

Analytic rubrics list separate levels of performance for each criterion so that assessors can assess students’ performance on each criterion individually. The scales of analytic rubrics tend to focus on important dimensions related to performance criteria. Analytic rubrics are commonly used in assessing engineering assessments (University of Michigan, n.d.).

Figure 2: Example of Analytic Rubrics (Accessed from Rogers, 2010)

Work Effectively in Teams				
	Unsatisfactory 1	Developing 2	Satisfactory 3	Exemplary 4
Research & Gather Information	Does not collect any information that relates to the topic.	Collects very little information--some relates to the topic.	Collects some basic information--most relates to the topic.	Collects a great deal of information--all relates to the topic.
Fulfill Team Role's Duties	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.
Share in work of team	Always relies on others to do the work.	Rarely does the assigned work--often needs reminding.	Usually does the assigned work--rarely needs reminding.	Always does the assigned work without having to be reminded.
Listen to Other Teammates	Is always talking--never allows anyone else to speak.	Usually doing most of the talking--rarely allows others to speak.	Listens, but sometimes talks too much.	Listens and speaks a fair amount.

References:

- Mueller, J. (2012). Authentic assessment toolbox. Retrieved from http://jfmueller.faculty.noctrl.edu/toolbox/rubrics.htm
- Rogers, G. (2010). Developing rubrics. Retrieved from http://www.abet.org/uploadedFiles/Events/Webinars/Developing_Rubrics.pdf
- University of Michigan. (n.d.). Rubrics, scoring & grading. Retrieved from http://www.engin.umich.edu/teaching/assess_and_improve/handbook/direct/rubric.html

Online tools for creating rubrics

Online rubrics are convenient and easy to use. Online rubrics are web-based software that allows users to develop custom rubrics, 4-point rubrics, instant rubrics, or use the templates offered on the online rubrics website to create preformatted rubrics. With the online rubrics, lecturers can give feedback and even build up a database of rubrics archive for various assessments (Assessment Resource Centre (HKU), 2009). Rubistar (n.d.) and Rubrics Maker (n.d.) are two online tools that can be used to create and edit rubrics.

References:

- Assessment Resource Centre (HKU). (2009). Assessment tools. Retrieved from http://ar.cetl.hku.hk/tools.htm
- Rubistar. (n.d.). Create rubrics for your project-based learning activities. Retrieved from http://rubistar.4teachers.org/index.php
- Technology's Platinum Membership. (n.d.). Rubrics maker. Retrieved from http://www.makeworksheets.com/samples/rubrics/index.html.

Developing Rubrics for Engineering Education

The process of developing rubrics within engineering courses can be exhaustive. There are various steps involved in the developmental process of rubrics. The following section will explore the procedure in developing rubrics and will provide tips in developing rubrics.

Guidelines in developing rubrics

1. Identify the purposes and aims of assessing the students: Determine if it is for feedback and/or for certification or others. See "Assessment in Higher Education" (http://ar.cetl.hku.hk/assessment.htm) for more details.

2. Identify what you want to assess: Align them with the students' learning outcomes and objectives and learning activities.

3. Select the appropriate rubrics: Determine whether holistic rubrics or analytic rubrics are more appropriate. The selection depends on the type of assessment used and the specific results you want to provide for feedback in the outcome assessment process.

4. Identify the performance criteria that your assessment will be graded against: For example for presentation rubrics, you may have introduction, knowledge understanding, presentation delivery, posture/eye-contact and time-management.

5. Identify the type of scale to be used: Identifying an appropriate scale is essential both in terms of the number of levels and the type. For instance a scale of 1-0 will not be useful, and a scale of 10 levels will probably cause frustration for the evaluator and become too exhaustive. When adopting the use of "0" in the number scale, it is important to take precaution as a student who receives a "0" may have the tendency to feel that he or she receives a grade of "zero". It may be more useful to use scales with words such as "Excellent, Proficient, Average and Poor"

6. Describe the level of mastery: Write descriptive statement(s) for each level of performance, the difference between each level should be as equal as possible. The best way to do that is to determine the worst and the best levels, and try to fill the

levels in between. In addition, the description of the levels should be objective than subjective. For instance, a descriptive statement like “Student’s mathematical calculations contain no errors” is better than a descriptive statement like “Student’s mathematical calculations are good”. The first statement is preferred over the latter statement because the phrase “no errors” is quantifiable, whereas “are good” requires the evaluator to make judgment.

7. Test the rubrics: Conduct a test trial of the scale on several samples with several faculty members using the developed rubrics. In order to determine the inter-rater reliability of the rubrics, use formal statistical tests or at least draw up a rating matrix containing ratings of all raters and look for signs of reasonable consistency among all raters.

8. Put the rubrics into application: After conducting the test trials, the rubrics can be used in the formal assessment process.

9. Revise the rubrics from time to time: Discuss with fellow colleagues and students when revising the rubrics. Others opinion can offer you insights on how to improve your rubrics. Therefore it is wise to enlist the help of colleagues when developing rubrics for the assessment of a program. Rubrics function to promote shared expectations and grading practices, which can be beneficial to both faculty members and students in the programme.

10. Options: It is sometimes useful to develop the rubrics with the students, as it helps the students to understand the usefulness of rubrics and allowing transparent assessment procedures.

Tips on developing rubrics

1. Find and adapt existing rubrics: The chance of finding rubrics that matches exactly to your program or course is rare. However if you want to save time, you can choose to adapt existing rubrics where you make minor modifications to the rubrics to match your own assessment. If not, you can seek other fellow colleagues to see if they have developed a set of rubrics of their own to gain insights on developing your own set of rubrics.

2. Evaluate the rubrics: In order to evaluate your rubrics critically, you can try answering the following questions during the process: (a) Do the rubrics target the outcome(s) being assessed? (If the rubrics do, then you have developed some successful rubrics); (b) Do the rubrics address anything extraneous? (If the rubrics do, then delete those extraneous areas) (c) Are the rubrics useful, feasible, manageable, and practical? (If the answer is yes, then you can find multiple ways to use the rubrics i.e. for grading assignment, peer review, and students' self assessment, etc.)

3. Gather reference samples from student that exemplifies each point on the scale: Rubrics become meaningful to a student or colleague when the benchmarks, anchors, or exemplars are available.

4. Be prepared for any necessary revision of the rubrics at all times: As the developer of the rubrics, you have to bear in mind to revise your rubrics on a timely basis.

5. Share your rubrics, when you have developed good rubrics: Sharing your rubrics among your fellow colleagues can enhance interaction across academic faculty members and in return you might get beneficial constructive feedbacks from your colleagues on how to improve your rubrics.

6. Grade Moderation: Share your rubrics with teachers from the same course conducting the same assessment to prevent grade inflation or deflation, and thus help achieve consistency in assessment.

References:

- Mertler, C. A. (2001). Designing scoring rubrics for your classroom. *Practical Assessment, Research and Evaluation, 7*(25). Retrieved from http://www.pareonline.net/getvn.asp?v=7&n=25
- Seybert, J. A. (2012). Using holistic rubrics to assess general education learning outcomes. Retrieved from http://planning.iupui.edu/988.html
- University of Hawaii at Manoa. (n.d.). Creating and using rubrics. Retrieved from http://manoa.hawaii.edu/assessment/howto/rubrics.htm#p4
- University of Hawaii at Manoa. (n.d.). Creating and using rubrics: Tips for developing a rubric. Retrieved from http://manoa.hawaii.edu/assessment/howto/rubrics.htm#p8

The Role of Rubrics in Engineering Education

Various practitioners have sought to develop their own rubrics to accommodate certain factors within their rubrics. In the following section, some case studies will be presented on the role of rubrics in engineering education.

Assessing Global Competency in Engineering Education using Rubrics

The awareness of incorporating global competency within the engineering programme is gaining increasing popularity. Global competency is the awareness and interest in learning about the world and its function. Although assessment of such competency within engineering programmes has brought attention among scholars, studies featuring exhaustive methods for assessing competencies with respect to professional practice within the academic discipline have been minimal. Aspects of global competency have also been specified in the ABET outcome criteria.

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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d. an ability to function on multidisciplinary 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 (both oral and written)
h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, 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.

Given the importance of incorporating global competency within engineering programs, the following study conducted by a professor from California Polystate University (DeTurris, 2012) aims to develop rubrics that assess global competency in relation to the ABET outcomes namely (c), (h), (j) and (k). The proposed rubrics encompass both the technical and professional skills essential in assessing global competency with respect to the four outcomes. It also includes a spectrum for attitudes, knowledge and skills, an examination of an internal frame of reference and behavioral observation. The skills in relation to global competency are categorized in terms of awareness, perspectives, and participation for each of the four outcomes with an expanding scale of capability.

References:

- DeTurris, J. D. (2012, April). *Assessment rubrics for global competency in engineering education*. Paper presented at the Proceedings of the 2012 ASEE PSW Conference, San Luis Obispo, California.

Developing and Using Rubrics to Evaluate Subjective Engineering Laboratory and Design Projects

The study conducted at Iowa State University's Faculty of Aerospace Engineering and Engineering Mechanics (Kellog, Mann, & Dieterich, 2001) discusses the process of developing and refining the rubrics for engineering design courses and laboratory courses. Apart from the development and refinement of the rubrics, the discussion also covers observations and feedback from faculty and teaching assistants using the rubrics and the results from the student summative survey data, which includes the implemented changes that address student concerns.

Developing rubrics are never an easy task because the process involves a lot of trial and error, which challenges the developer's patience. Besides developing rubrics, refinement is also crucial. A good indicator suggesting rubrics need refinement is when the teacher feels that the best piece of work is not receiving the best grades. Although developing and refining rubrics are exhaustive, the results from the study revealed that faculty and teaching assistants all appreciate the use of the rubrics as a way to ensure that the grading are unified and to describe standards for completing assignments. However the summative survey

results from students revealed a mixed response about the use of rubrics. The seniors were positive about the rubrics in which they even asked for rubrics, whereas sophomores were less pleased with the rubrics.

The hypothesis for such varied response is because the seniors have developed certain familiarity with rubrics, thus the direction offered by the rubrics could be easily interpreted into their actions. In addition, the seniors considered the rubrics invaluable because it provided them guidance on how to document their work. In contrast with the seniors, the sophomores had the tendency to perceive the rubrics to be a checklist for their laboratory report that was used to punish them. Many of the responses were very performance-oriented. They felt that the rubrics aimed at providing them a guideline, which directs them how to do something rather than providing them with examples of what they should do. Some responses stated that they believed they had met the criteria in the rubrics, yet they still received poor grades.

The following are summative observations from the faculty in their development and implementation of the rubrics.

(1) It is observed that the key factor to the success or failure of the rubrics used in the laboratory course depends on how the teacher applies the rubrics and how well students were educated on the use of the rubrics. Seniors did not need much guidance and discussion about the rubrics compared to the sophomores.

(2) Another key to its success is students' experience with the material. Students who have not had the experience of writing an assignment like technical reports should be offered materials like sample reports or checklists along with the rubrics so that they can understand what is expected with an assignment.

(3) The faculty refined the rubrics as the semester progressed by changing the weighting of the objectives. This emphasized the higher-level skills, the quality of content as the semester proceeded and the students' mastery of the "mechanical aspects of reporting technical information" (Kellog et al., 2001, p. 8).

(4) Collaboration among teachers in the development and implementation of the rubrics seems to be important in standardizing grading. For design courses, the teachers and the teaching assistant discussed the rationale behind the objectives and criteria for the rubrics. Examples of evaluated reports using the rubrics were given to the teaching assistants.

However for the laboratory courses, such measure has not been adopted. Thus students have commented about the inconsistency of grading in the laboratory courses with different teachers using the rubrics.

(5) When students become accustomed to the use of rubrics, they can provide invaluable feedback in the refinement process of the rubrics. The students in each of the courses provided sufficient feedback and opinions from the summative survey results. Some of which facilitated the refinement process. For instance it was evident, that sophomore students needed extra support and detail on the use of rubrics.

References:

- Kellog, R. S., Mann. J. A., & Dieterich, A. (2001, June). *Developing and using rubrics to evaluate subjective engineering laboratory and design projects*. Paper presented at the 108th ASEE Annual Conference and Exposition, Albuquerque, New Mexico.

Developing Analytic and Holistic Rubrics to assess Students' Knowledge associated to the Learning Outcomes of the Scenario Assignments in Engineering

McMartin, McKenna, & Youseffi (2000) describe the use of a scenario assignment in teaching non-freshman students in a Mechanical Engineering course at the University of California, Berkeley. The scenario assignment is basically a qualitative performance assessment tool created to assess students' knowledge of teamwork, engineering practices, and problem solving. Students were offered the scenario to describe a "day in the life" problem faced by engineers. Students were asked to describe the process or plan they would adopt in finding the solution to a technical or design problem as a team instead of just solving the problem presented in the scenario in terms of analyzing appropriate models, running simulations, and converging on a correct recommendation.

Analytic and holistic rubrics were developed to assess students' knowledge with respect to the learning outcomes associated with the scenario assignment. Initial findings suggest that the scoring of the scenarios using analytic rubrics facilitated faculty in figuring out students' strengths and weaknesses quickly. In addition to figuring out the strengths and weaknesses, the analytic rubrics can also assist the faculty in adapting their course to address the areas where students need attention. For holistic rubrics, the rubrics can be easily used to assess

the changes in students' learning and development over time and across a curriculum. However, the holistic rubrics fail to provide definitive details regarding the achievement of learning outcomes i.e. the ability to solve open-ended problems or the ability to work in an inter-disciplinary team. Therefore the creators of the rubrics took the initiation of developing analytic rubrics to resolve the problems in holistic rubrics. Figures 1 and 2 presented below shows the rubrics the creators have developed for the scenario assignment.

Figure 1: An example of holistic rubrics for the scenario assignment (Accessed from McMartin et al., 1999)

Criteria for demonstrating open ended problem solving

(a) Student recognises and determines when a problem is worth solving (develops decision making criteria; justifies decisions.)

(b) Student defines (frames) problem accurately (analyses critical elements and scope of problem, focuses on issues, sorts issues according to impact on problem.)

(c) Student articulates social, economic, and technical constraints of a problem.

(d) Student devises process and work plan to solve problem (identifies critical tasks, time needed, and resources; uses organisational and management tools; divides work efficiently.)

(e) Student identifies, considers, and weighs options or consequences of plan and design (identifies analytic strategy to weigh design consequences and solutions.)

Criteria for demonstrating multidisciplinary teamwork

(f) Student negotiates various design approaches with a multidisciplinary group/team (identifies different needed disciplinary expertise to solve the problem, creates multidisciplinary team.)

(g) Student leads or follows when appropriate to the needs of the group (shares stage, offers expertise/participation when and where appropriate.)

Total Score _____

Scoring guide: “1” = incompetent: fails to meet criteria;

“2” = limited: meets few criteria to a limited degree;

“3” = adequate: meets some criteria to an adequate degree;

and “4” = sophisticated: meets most of all criteria to an exceptional degree.

Figure 2: An example of analytic rubrics for the scenario assignment with a focus on criteria (d) (Accessed from McMartin et al., 1999)

Criteria (d): Student devises process and work plan to solve problem	
Measure	**Score**
fails to identify the critical tasks and actions necessary to solve problem; fails to identify and misidentifies the time and resource requirements; does not employ organisational or management tools to organise tasks and resources	1
identifies few of the critical tasks and actions necessary to solve problem; identifies few, or misidentifies the time and resource requirements; employs few organisational and management tools to organise tasks and resources	2
identifies some of the critical tasks and actions necessary to solve problem; identifies some of the time and resource requirements; sometimes employs organisational and management tools to logically and efficiently organise tasks and resources	3
identifies all critical tasks and actions necessary to solve problem; identifies most time and resource requirements; always employs organisational and management tools to logically and efficiently organise tasks and resources	4

References:

- McMartin, F., McKenna, A., & Youssefi, K. (1999, November). *Establishing the trustworthiness of scenario assignments as assessment tools for undergraduate*

engineering education. Paper presented at the 29th ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico.

- McMartin, F., McKenna, A., & Youssefi, K. (2000). Scenario assignments as assessment tools for undergraduate engineering education. *Education, IEEE Transactions*, *43*(2), 111-119.

When to use Holistic Rubrics and Analytic Rubrics?

The choice between using holistic rubrics or analytic rubrics depends on a variety of factors such as the type of assessment, the learning outcomes, the feedback that the teacher wish to provide and others.

The tendency to use holistic rubrics is when the teacher wants to make a quick or gross judgment. For instance if an assessment is like a brief homework assignment, applying a holistic judgment maybe already sufficient (i.e. check or cross) to quickly review students' work. In addition, holistic rubrics are used when a single dimension is adequate to understand students' performance. Holistic rubrics are commonly applied to many writing rubrics because they are not easy to differentiate clarity from organization or content from presentation. Thus some educators believe holistic assessment of students' performance can better capture students' ability on certain tasks.

The tendency to use analytic rubrics is when the teacher wants to typically assess each criterion separately, especially for assignments that involve a larger number of criteria. Analytic rubrics can better handle cases when it becomes extremely difficult to assign a level of performance as the number of criteria increases because as student performance varies increasingly across criteria, assigning an appropriate holistic category to the performance becomes difficult. Moreover, the use of analytic rubrics may also be initiated by the following reasons i.e. the need to see the relative strengths and weaknesses of a student; the need to assess complicated skills or performance; the need for detailed feedback to drive improvements; or the need to initiate students to self-assess themselves in their understanding and performance.

References:

- Mueller, J. (2012). Authentic assessment toolbox. Retrieved from http://jfmueller.faculty.noctrl.edu/toolbox/rubrics.htm
- Rogers, G. (2010). Developing rubrics. Retrieved from http://www.abet.org/uploadedFiles/Events/Webinars/Developing_Rubrics.pdf

Benefits and Drawbacks of Holistic Rubrics and Analytic Rubrics

In developing and using both analytic and holistic rubrics, it is important to realize their advantages and disadvantages especially in designing the rubrics so that the designed rubrics serve the intended purpose. Therefore the following section will explore some of the benefits and drawbacks of the two rubrics respectively.

Benefits of Holistic Rubrics

1. Holistic rubrics are normally written generically and can be used with many tasks.
2. The use of holistic rubrics saves time as it minimizes the number of decisions required for the teacher to make.
3. Trained teachers have the tendency to apply them consistently, which results in more reliable measurement.
4. It can be easily used to assess the changes in students' learning and development over time and across a curriculum.

Drawbacks of Holistic Rubrics

1. The holistic rubrics cannot provide the teacher and the student specific feedback about the strengths and weaknesses of the students' performance.
2. The following may suggest that the rubrics is developed poorly when the performances meet the criteria in two or more categories, thus selecting the one with the best description would be tough.
3. Criteria within the rubrics cannot be differentially weighted.

Benefits of Analytic Rubrics

1. Analytic rubrics can provide the teacher and the student specific feedback about the strengths and weaknesses of the students' performance (unlike holistic rubrics).
2. The dimensions within the analytic rubrics can be weighted to reflect relative importance.
3. When the same rubrics' categories are used repeatedly, the analytic rubrics can show progress over time in some or all dimensions.
4. More useful for grade moderation.

Drawbacks of Analytic Rubrics

1. Compared to holistic rubrics, creating and using analytic rubrics are less time efficient.
2. Increased possibility of disagreement among evaluators. Harder to achieve "intra-rater reliability" and "inter-rater reliability" on all of the dimensions within the analytic rubrics compared to a single score yielded by holistic rubrics.

References:

- Rogers, G. (2010). Developing rubrics. Retrieved from http://www.abet.org/uploadedFiles/Events/Webinars/Developing_Rubrics.pdf