AC 2007-803: MEASURING STUDENT ABILITY TO WORK ON MULTIDISCIPLINARY TEAMS: BUILDING AND TESTING A RUBRIC

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Measuring Student Ability to Work on Multi-Disciplinary Teams: Building and Testing a Rubric

Engineering educators struggle to provide effective educational experiences for professional skills such as communication, cultural awareness, and ability to work on multi-disciplinary teams. As difficult as these skills are to teach, they are even more difficult to assess. Montana State University (MSU) is embarking on curricular change to enhance students' multi-disciplinary learning experiences. As one of our first steps, we developed multi-disciplinary learning objectives for our students so that we will have a way to chart our progress. We have tested more than one possible method of determining both a baseline measure and future measures of student learning related to these objectives.

This paper discusses briefly the background of multi-disciplinary engineering education at MSU and also mentions the multi-disciplinary study we have conducted over the past 18 months.[1] We offer our student learning outcomes for multi-disciplinary skills, which were developed collaboratively, and also recount our failed attempt at establishing a baseline for these outcomes with a fictional scenario and series of questions to which students wrote responses. The main focus of the paper is the development of a multi-disciplinary rubric, a tool that other programs may be able to adapt for their own use. The paper includes a summary of some of the literature about developing rubrics and a description of the process we used to design and test the rubric. Also included are results from a pilot test conducted in autumn of 2006, some usability input from faculty, and our future plans for using the rubric.

Background

A few years ago, the College of Engineering at MSU began offering a multi-disciplinary design opportunity for the senior design project. This program, the "No Walls" program, offered students a multi-disciplinary experience as a substitute for their discipline's capstone course(s). No Walls project teams were composed of students from at least two different programs in the college, including computer science. During the 2005-2006 academic year, a group of faculty, led by the second author, conducted a study of how to move forward with multi-disciplinary education in the college. The result of that study is that we will be requiring a junior-level design course, which will be developed and implemented over the next few years.

Part of the work conducted during 2005-2006 included developing learning outcomes for multi-disciplinary teamwork skills. In other words, what did we want our students to be able to do at graduation in regard to working on a multi-disciplinary team? These learning outcomes, developed by the Multi-Disciplinary Advisory Committee that included faculty representatives from most of the college's programs, are listed below:

- View engineering projects from a systems perspective.

- Recognize and appreciate trade-offs across disciplinary perspectives.
- Communicate technical and other trade-offs, and negotiate satisfactory resolution.
- Generate creative, integrated and effective solutions collaboratively.

We agreed that our ultimate goal would be to include students from outside engineering in our junior-level, multi-disciplinary design course, but that we would begin by defining "multi-disciplinary" as inclusive of all college of engineering programs, including Mechanical Engineering Technology and Computer Science.

Assessing the Ability to "Function on a Multi-disciplinary Team"

Parallel to the process of choosing an alternative for providing our students with a multi-disciplinary educational experience, we have been ruminating about how to determine a baseline for our outcomes as well as a method for measuring future progress in regard to these outcomes. One faculty member's comment early on ("How do we know we're not already doing a good job in this area?") haunted us. A fairly recent article on the teaching and assessment of professional skills noted that "There have been important strides in developing rigorous assessment tools and conducting effective outcomes studies" for an ability to function on a multi-disciplinary team, but "the literature remains sparse with respect to robust, effective measures for these outcomes."[2]

Some related work has been done, but most of that work focuses on teamwork in general, whereas our outcomes are specific to multi-disciplinary teams. For example, McGourty and De Meuse focused on general teamwork skills in their computer-based "Team Developer."[3] For assessment related to their interdisciplinary certificate in product realization, the University of Pittsburgh uses The Team Developer, but also uses a student course evaluation, concept maps, and a project scoring rubric. The rubric is used by industry and academic judges and has four primary areas and 12 elements, including project goals, creativity and innovation, prototype, organization and clarity of the oral presentation, and ability to answer questions.[4] Another rubric was developed at Colorado School of Mines to assess their Engineering Projects in Service (EPICS) final reports.[5] Others have recommended using pre- and post- student questionnaires as well as surveys of alumni[6] to assess teamwork skills.

Although this previous work was instructive, none of these previously developed tools was a good fit for our context. Because we had established specific multi-disciplinary outcomes for an organically grown multi-disciplinary experience, we determined that although we could learn from previous efforts, particularly in the area of teamwork, we would have to develop our own method of assessing progress.

In the following sections, we recount two attempts at developing a measure for our multi-disciplinary objectives.

A Scenario-Based Assessment Tool

In spring of 2006, we developed two versions of a scenario-based assessment tool, one for mechanical engineering and one for electrical engineering (see Appendix A for the mechanical engineering version of the tool). These tools asked students to respond to several questions after reading a short scenario. We tested the tool on 28 mechanical engineering seniors and 31 electrical engineering seniors at the end of spring semester 2006, after they had completed their senior design project. We also asked our Engineering Advisory Council, composed of professional engineers working in industry, to complete one of the scenarios, whichever was closest to their area of expertise. We received seven responses from the advisory council members.

The results from this test convinced us that the tool was not sufficiently discriminating. Very few of these students had been involved in a multi-disciplinary senior design project, and none had worked with students with marketing backgrounds; however, students used common sense to articulate the most obvious issues that would be of interest to marketing and production, and they actually came up with some creative responses to the two problems. On the other hand, the responses from the professional engineers were not qualitatively or quantitatively different from the student responses to any great degree, possibly because they did not have sufficient time to devote to completing the exercise during the advisory council meeting.

We determined that a scenario-based tool would be difficult to score and would not give us useful information about levels of performance. After some discussion, we decided that a rubric might be more appropriate for our purpose.

Developing a Rubric

In order to get more background on developing measures of performance, one of the authors attended a workshop on Designing Performance Measures at Washington State University. The workshop, which helped us get started on a rubric and gave us a model of a development process, was sponsored by the Northwest Regional Professional Development Center and facilitated by Pacific Crest personnel.

A rubric is a scoring guide used to evaluate the quality of student work. Rubrics have been used extensively in the evaluation of student writing and, more recently, in the evaluation of many different types of student work, including oral presentations and group projects. Rubrics have three important characteristics: evaluative criteria, quality definitions, and a scoring strategy.[7] Evaluative criteria are dimensions or attributes of quality in the work being judged. For example, in a writing rubric, evaluative criteria might include content, organization, style, and grammar. Quality definitions or levels of mastery are descriptions of various levels of quality in each of the criteria. Thus, engineering rubrics often use terms such as novice, apprentice, and professional. Other possible terms for levels of mastery are not acceptable, competent, and excellent. Finally, rubrics involve a scoring strategy. Holistic scoring is often used in the case of writing. Holistic scoring involves assigning a single score (for example, a 1, 2, or 3) after consideration of all of the criteria. Analytic scoring requires scores for each of the criteria, and those individual scores may or may not be rolled up into a final single score.

One advantage of a rubric is that it can be used not only to evaluate student work but also to educate students.[8] The rubric can be used to teach students disciplinary standards and also to introduce them to the elements involved in levels of quality of engineering work, thus helping them to judge and improve their own work. A rubric, when given to students in advance, can be a catalyst for conversations about disciplinary skills.

Another advantage of a rubric is that its development engenders useful and insightful conversation among faculty. These discussions can move a program toward higher consistency in evaluating student work, which in turn increases student satisfaction and trust.

Our first task was to develop a description of multi-disciplinary teamwork. We included in this definition the learning outcomes we had previously developed. Our description is below:

> Multi-disciplinary teamwork is a set of interdependent and synergistic processes, guided by shared goals that lead to meaningful outcomes. Multi-disciplinary engineering teamwork is productive only in a respectful environment that is engaging to all members. An effective team member views engineering projects from a systems perspective and recognizes, appreciates, and communicates technical and other trade-offs across disciplinary boundaries. Team members are able to negotiate satisfactory resolutions to constraints, trade-offs, and conflict, and are able to generate creative, integrated, and effective solutions collaboratively.

Our next task was to develop a list of "key attributes" for effective performance on a multi-disciplinary team. At the Designing Performance Measures Workshop previously mentioned, the group developed a rubric for an individual's performance on a team. We were able to leverage that work by using some of the criteria or "key attributes" from that process. The two authors added attributes to the list, then we gave the list to the members of the Multi-disciplinary Advisory Committee to help us rank the list. Our ultimate goal was to pare the list down to 10 key attributes in order to render the rubric more usable.[9] The complete list of attributes is shown in Table 1 below:

Table 1: Key Attributes for an Individual's Performance on a Multi-Disciplinary Team

Interpersonal communication (includes listening, oral, and written): Effective communication would be timely, courteous, and complete.

Collaboration/cooperation: ability to work together toward a common end or purpose; to acquiesce willingly when necessary, be willing to not only share problems and progress on one's work but to pick up the slack and help others when necessary.

Accountability/reliability: willingness to accept responsibility or to account for one's actions and do so in a consistent and timely manner.
Role performance: ability to completely understand one’s role and to adhere to that role.
Inclusive decision making: willingness to include everyone in the process of making decisions.
Understanding and communicating disciplinary trade offs: An ability and willingness to articulate one’s own disciplinary point of view to others without a similar disciplinary background.
Common goals/shared outcomes: the individual’s buy-in and follow-through on established goals and outcomes. May include the process of developing these goals and outcomes.
Conflict management and resolution: An awareness of the value of substantive (rather than personal) conflict, particularly during the creative phase of a project and an ability to identify when the conflict needs to be resolved in order to move ahead toward final goals and outcomes.
Documentation: Ability to keep notes and thoroughly document one’s work and the progress of the team.
Reflection on individual and team process/assessment: An awareness of one’s own strengths and weaknesses in the team process as well as an awareness of the effectiveness of the team process and how it might be improved.
Empathy for diverse perspectives: True awareness of the priorities and constraints inherent in other disciplines represented on the team and acceptance of the validity and value of personal differences in approaching a problem.
Planning/organization: An understanding of how to manage one’s own time and also how to contribute to the management of the project as a whole.
Leadership: Ability to inspire, mentor, and influence others to do their best work in accomplishing the goals and objectives of the team.
Intrinsic motivation: An internal desire and determination to perform one’s own role to the best of one’s ability.
Effort / time commitment to project: Level of energy devoted to the project—going the extra mile.
Willingness to learn: Openness and even a desire to learn from others and to conduct independent research into new topics.
Good fit between individual background/interests and project objectives

We asked the faculty on the committee to make a series of pair-wise comparisons, using one of the attributes (conflict management and resolution) as the basis for the comparison. See below for the example:

Please indicate your judgments about the importance of the above attributes for working effectively in a multi-disciplinary team environment, in relation to one attribute in the set:

1. Conflict management and resolution

Indicate the relative importance of each attribute by circling one of the numbers on the right. For example, if you circle "+4" on the first line, you would be indicating that in your judgment accountability/reliability is much more important than conflict management and resolution.

	Much Less Important		Slightly Less Important				Slightly More Important		Much More Important	
2. Accountability/reliability	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
3. Collaboration/cooperation	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
4. Common goals/shared outcomes	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5

Nine faculty members made the pair-wise comparisons. One faculty's scores were not used because most of the attributes were rated as equal to "Conflict Management and Resolution." Average scores and standard deviations were computed and are shown in the table below. The attributes have been ordered from most important to least important, with Conflict Management and Resolution inserted at the **0.00** mark, according to the averages.

Table 2. Results from pair-wise comparison of attributes, including average, standard deviation, and rank.

Attribute	Average	Std Dev	Rank
Understanding/communicating disciplinary tradeoffs	1.750	2.188	1
Interpersonal communication	1.375	2.066	2
Collaboration/cooperation	1.250	1.282	3
Planning/Organization	1.250	1.389	4
Accountability/Reliability	1.125	1.642	5
Willingness to Learn	1.125	2.031	6
Empathy for diverse perspectives	0.875	2.357	7
Common goals/shared outcomes	0.750	1.982	8
Inclusive decision making	0.250	1.581	9
Conflict management and resolution	n/a	n/a	10
Documentation	-0.375	2.134	11
Leadership	-0.429	2.440	12
Effort/time commitment	-0.500	2.673	13
Role performance	-0.500	1.773	14
Reflection/assessment	-1.000	2.507	15
Intrinsic motivation	-1.625	1.923	16
Fit between student background and project objectives	-2.375	2.560	17

We proceeded to choose our top ten attributes according to the average ratings, including **conflict management and resolution**, which landed in the 10^{th} spot. As a cross check, we sorted each rater's scores individually, counted the number of times each attribute fell in a rater's top 6, then re-ranked the attributes. Some of the attributes switched places, but the same 10 appeared at the top of the ranking. Seven of the top 10 attributes, as determined in step 1, occurred in the bottom six of at least one of the raters.

This methodology represents one possible way to arrive at a set of key attributes for a rubric. Another approach that is more commonly used is to arrive at consensus in a series of face-to-face meetings with a group of stakeholders. We chose our approach because (1) we felt we had depleted the time and energy of our Multi-disciplinary Advisory Committee in the previous year's series of meetings, (2) one of the authors had attended a workshop that gave us a head start on developing the rubric, and (3) we were on a tight time schedule for testing the rubric prior to implementing a new required course for students.

In the end, we feel confident about the validity of the approach in distinguishing more important attributes from less important. However, readers should realize that rubric development is a context-dependent process, and another group of faculty members at another institution might rank key attributes for an individual's performance on a team differently.

After determining our top ten attributes, we paired the attributes to create five evaluative criteria, which are listed below:

Interpersonal communication and collaboration
Understanding and communicating disciplinary tradeoffs and empathy for diverse perspectives
Planning/organization and accountability/reliability
Common goals/shared outcomes and conflict management and resolution
Willingness to learn and inclusive decision making

Pairing the attributes was a strategy learned at the Designing Performance Measures Workshop, and the strategy is consistent with suggestions in the literature to keep the rubric as simple as possible.

After pairing the attributes, five levels of performance were defined for each pair of evaluative criteria:

1. Team Catalyst
2. Team Player
3. Contributer
4. Group Member
5. Individualist

The performance level names also resulted from the previously mentioned workshop. Descriptors are not absolutely necessary, but do help to visualize levels of performance.

As an example, the full descriptions for each level of performance for "Understanding and Communicating Disciplinary Tradeoffs and Empathy for Diverse Perspectives" are given below:

Understanding & communicating disciplinary tradeoffs and empathy for diverse perspectives

Team Catalyst: Values disciplinary and personal style differences and promotes the use of these differences in team processes in order to produce a higher quality outcome.
Team Player: Understands disciplinary and personal style differences and supports the use of these differences in team processes.
Contributer: Willing to take into account disciplinary and personal style differences in team processes.
Group Member: Has a limited understanding of the value of disciplinary and personal style differences and limits the effectiveness of the team's work by not accounting for these differences.
Individualist: Does not value or understand disciplinary and personal style differences and hinders the effectiveness of the team by not supporting these differences.

These full descriptions were developed by the authors rather than by committee.

Another way to view the rubric is by grouping all descriptions of the same performance level. This grouping is shown below for the middle performance level, Contributer, for illustration purposes.

Level 3 Contributor
Adds to team unity by listening well, sharing ideas, contributing to team communications, and assisting in producing outcomes. (Interpersonal communication and collaboration)
Willing to take into account disciplinary and personal style differences in team processes. (Understanding and communicating disciplinary tradeoffs and empathy for diverse perspectives)
Plays a supporting role in planning and tracking the team's work and is generally reliable for contributions to the team (Planning/organization and accountability/reliability)
Appreciates the positive potential of conflict but makes limited use of it in developing and attaining common goals. (Common goals/shared outcomes and conflict management and resolution)
Contributes to decisions and is open to learning from working with others. (Willingness to learn and inclusive decision making)

The format of the actual rubric, shown below, allowed for the user to circle a number that corresponded to the level of performance for each evaluative criterion:

Circle the number on the right that corresponds with the best description for the student's performance in this area.

Understanding & communicating disciplinary tradeoffs and empathy for diverse perspectives 1. Values disciplinary and personal style differences and promotes the use of these differences in team processes in order to produce a higher quality outcome. 2. Understands disciplinary and personal style differences and supports the use of these differences in team processes. 3. Willing to take into account disciplinary and personal style differences in team processes. 4. Has a limited understanding of the value of disciplinary and personal style differences and limits the effectiveness of the team's work by not accounting for these differences. 5. Does not value or understand disciplinary/personal style differences and hinders the effectiveness of the team by not supporting these differences.	1	2	3	4	5

Testing the Rubric

Faculty in mechanical engineering, mechanical engineering technology, and electrical and computer engineering were asked to use the rubric when evaluating student capstone design projects. The rubrics were used to evaluate an individual, not a team. A total of 47 rubrics were completed.

Most of the projects and project teams were not multi-disciplinary; however, three of the teams included students from different degree programs: two teams included mechanical engineering and mechanical engineering technology students, and one team included electrical engineering and computer engineering students. Although differences in the disciplines within these teams are not as pronounced as differences among some engineering disciplines, the students did come from different programs, so some differences in background, perspective and expectations might be expected.

Initially, we did not expect that multi-disciplinary team scores would be significantly different from the scores of single discipline teams. However, a two-tailed t-test on the difference in means detected statistically significant differences in all but one criterion, as shown in Table 3.

Table 3. Comparison of rubric mean scores between teams that were not multi-disciplinary and those that were. (Note that "1" is the best possible score and "5" is the worst possible score.)

Evaluative Criteria	Mean Single Discipline (n=36 or 33)[a]	Mean Multi-Disciplinary (n=11)	P-value from t-test
Interpersonal communication and collaboration	2.083	3.000	.009
Understanding and communicating disciplinary tradeoffs and empathy for diverse perspectives	2.182	3.273	.003
Planning/organization and accountability/reliability	1.917	2.545	.112
Common goals/shared outcomes and conflict management and resolution	2.061	3.273	.0001
Willingness to learn and inclusive decision making	2.000	2.727	.007
Overall	2.061	2.818	.022

[a] One evaluator did not give scores for two criteria and overall, so n=44 for those means.

The sample size is small, so these results are inconclusive; however, it is interesting that the students on multi-disciplinary teams scored lower on most criteria (had a higher, thus a better numerical mean). The difference could be attributed to variance in the faculty evaluators. On the other hand, the difference could mean that multi-disciplinary issues were more salient in those teams that included students who were not from the same program, and their performance was affected negatively. The two most significant differences were in "Understanding and communicating disciplinary tradeoffs and empathy for diverse perspectives" and "Common goals/shared outcomes and conflict management and resolution," which could easily be seen as the two criteria most affected by the presence of diverse disciplines on a team. If this is the case, it suggests positive evidence for the utility of the rubric.

Usability Feedback from Faculty

The faculty who used the rubric at the end of autumn 2006 were asked to give input on the rubric's usability via a brief web survey created in SurveyMonkey. The survey included the following questions:

1. On average, how long did it take you to complete the rubric for each student?
2. Was it easy to understand how to complete the rubric?
3. Did you have any trouble distinguishing between the levels defined within the rubric?
4. What suggestions do you have (if any) for making the rubric more usable?
5. Would you use the rubric in the future for evaluating students' performance on a multi-disciplinary team?
6. Would you find the rubric useful for peer assessment of performance on a multi-disciplinary team?

7. Would you find the rubric useful for student self assessment of performance on a multi-disciplinary team?
8. About how often did you meet with the project team for which you completed the rubrics?
9. About how long did you meet with the team when you met?

We were able to get responses from only three of the faculty who used the rubric. Two responded that it took five minutes or less to complete; one said five to ten minutes. All responded that it was easy to understand how to complete the rubric and that they did not have any trouble distinguishing between the levels of the rubric. Two responded that they would use the rubric in the future and one said "maybe." One responded that the rubric would be useful for peer assessment (two said "maybe"), and two responded that the rubric would be useful for self assessment (one said "maybe").

We will continue to use the rubric and to refine it from faculty feedback.

Future Work

The next step will be to test the validity and reliability of the rubric. We will scrutinize the rubric in the areas of content validity, construct validity and criterion validity. At the same time, we will work to determine and improve the rubric's inter-rater and intra-rater reliability, as recommended in the literature.[10]

We intend to use this rubric to assess the ability of our students to work on multi-disciplinary teams. We are particularly interested to measure the effects of implementing a junior-level multi-disciplinary design course, beginning with a pilot version in spring 2007.

The rubric could also be a valuable instructional tool, both in our new junior-level course and in the senior capstone courses. If the rubric is given to students in advance, it could help students understand the specific professional skills they will need to develop for multi-disciplinary teamwork in their future careers.

Acknowledgements

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Works Cited

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Appendix A: Multi-Disciplinary Scenario for Mechanical Engineering Students

Your team has been developing a helmet that has a built-in MP3 device for listening to music. Versions of the helmet could be used for skiing, snowboarding, bicycling, skateboarding, kayaking—any activity that normally requires a helmet. Your team includes you (a mechanical/materials engineer), an electrical engineer, a manufacturing engineer, and a marketing representative.

Please answer the following questions.

1. Each of the team members has a unique perspective on the work that you're doing, and there have been disagreements about how to proceed during the design process. What are the issues that might have come up from each team member's point of view? (List as many as you can think of.)

   Issues important to you as a mechanical/materials engineer:
   Issues important to the electrical engineer:
   Issues important to the engineer designing the production process for the product:
   Issues important to the marketing person:

Please don't return to the first page after completing it.

2. After looking at the prototypes, the marketing person was dissatisfied with the weight of the helmets, and would like you to come up with another prototype that is at least as lightweight (but as safe) as helmets without the electronics, which means using a different structure and material for the helmet. The material will be more expensive. You think it is doable, but will require several more months of prototype and testing than usual, which will delay market introduction, and may increase unit cost beyond the $149 price point determined by marketing unless the quality of the electronics is downgraded. Given this information, how would you proceed?

3. The project is already behind schedule and has no budget slack, and your team is in the hot seat with upper management. Failure to deliver on this project on time would be detrimental to your career with this company. Your proposed material for the helmet and lining has significant performance enhancement (safety!) over the existing design and has just undergone a manufacturing review. The manufacturing engineering group says your design—a new design that you've spent months developing, simulating, and refining—is unacceptable because it is to hard to produce, resulting in unacceptably high assembly costs, and could face reliability issues in the interface between the helmet and lining. You note that manufacturing buy-off is not required by company policy, and that the engineering release deadline is right around the corner. What would you do?