

Developing and using rubrics to evaluate subjective Engineering laboratory and design reports

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Abstract

In the past two years several faculty in Aerospace Engineering and Engineering Mechanics at Iowa State University have been utilizing rubrics to evaluate student work in laboratory courses as well as the engineering design course sequence. The laboratory course had primarily sophomores and the design course sequence were graduating seniors. Developing rubrics is not an easy task and requires iteration and patience. This paper will discuss how the rubrics were developed and refined. Observations and feedback from faculty and teaching assistants who are using the rubrics will be presented along with summative surveys data from the students. The faculty and teaching assistants uniformly appreciated the rubrics to ensure uniform grading and as a means to describe standards for completing assignments. The survey results from the students however show a difference between the group of primarily sophomores and the group of seniors who were graded using rubrics. The seniors were almost uniformly positive about the rubrics and even asked for rubrics while the sophomores were less satisfied with the rubrics. The results of the survey are presented and discussed along with changes that are being implemented to address student concerns.

Introduction

In the past two years several faculty in Aerospace Engineering and Engineering Mechanics at Iowa State University have been utilizing rubrics to evaluate student work in laboratory courses as well as the engineering design course sequence. These courses require students to prepare written and sometimes oral technical reports. These forms of communication, which are very important to the professional engineer, have often perplexed students who were unsure of the format and requirements of technical reports. Faculty, in turn, was faced with the overwhelming task of objectively evaluating work product of a very subjective nature. The use of rubrics appeared to be a practical solution to the dilemma encountered in these courses.

Rubrics are a form of authentic assessment that can be used on an ongoing basis during the teaching and learning process. A rubric is a matrix-like tool where the left-most column generally houses the desired performance skills or characteristics sought listed in the rows. The next column contains the criteria corresponding to the highest demonstration of each skill or characteristic. Each subsequent column contains criteria for lesser levels of performance.

Developing rubrics is not an easy task and requires iteration and patience. It is not unusual that a rubric will prove to be less than effective until it is tested. One of the best cues that a rubric needs refinement is when the instructor feels that the best reports are not receiving the best grades. Typically one designs a rubric by listing the desired performance or qualities that are sought. The designer then must consider a range by which to rate performance. These may be numerical or qualitative. Finally, the designer must define the characteristics and criteria by which the degree the objectives are met can be assessed. One useful tip is to list the criteria for the highest level of accomplishment for each objective¹. After the designer is satisfied by the criteria, each word that can vary should be circled. These are the words that will change as the criteria and characteristics for lesser levels of achievement are defined.

Rubrics provide many advantages in the assessment process. Rubrics force the instructor to clarify the criteria by which they will evaluate student work in specific and definite terms. When rubrics are designed and implemented carefully and correctly, they can facilitate more objective and consistent grading. Students are better aware of how their work will be evaluated and what the instructor expects. If the rubrics are designed according to standards of professional practice, the students will also begin to develop skills appropriate to their professional careers. Instructors can use rubrics to track the effectiveness of the instruction and to document the progress of the learners.

Rubrics in the laboratory course

Three faculty designed rubrics that were used in two multiple-section sophomore level laboratory courses. One laboratory course complimented the basic strength of material course and the other course was an introduction to aerospace instrumentation. The two main goals for using the rubrics were to provide students with explicit guidance in the preparation of their reports, oral presentations, and laboratory notebooks and to permit more consistent grading across sections and instructors. Rubrics allow instructors to define the criteria by which the report is evaluated, so that students know ahead of time what is important and how the instructor defines excellent, average, poor, or unacceptable work. A great deal of the subjectivity in grading is removed when criteria are explicitly defined. Thus, the rubrics are intended to provide the students with more feedback and a better understanding of the quality and acceptability of their work. In the rest of the paper, the rubrics for the aerospace instrumentation lab will be discussed.

Laboratory Course Rubric Content and Implementation

Rubrics were written for laboratory reports, oral reports, and laboratory notebooks. The laboratory report rubric evaluated the categories in (A) Objective Statement, (B) Experimental & Equipment Description, (C) Assumptions, (D) Results, (E) Figures, Plots, Tables, (F) Observations and Conclusions, (G) Sample Calculations, (H) Content and Appearance, (I) Style, (J) Organization, (K) Grammar, and (L) Analysis. The oral report rubric evaluated the categories (A) Introduction, (B) Transitions, (C) Handouts or Transparencies, (D) Voice, (E) Overall Style, and (F) Nonverbal Behavior. The laboratory notebooks evaluated the categories (A) Table of Contents, (B) Each Entry Signed, (C) Errors, (D) Notebook Storage, (E) Writing, and (F) Entry Content.

In each category of the rubrics, four values could be assigned to the student's work: High – 3 points, Medium – 2 points, Low – 1 point, and Unacceptable – 0 points. The rubrics were written by first describing what was expected for the High range. Then the next three ranges were described in terms of missing components of the High range. In some cases missing one element in a category reduced the assessment to a 1 while missing another element three times in that same category was required to reduce the assessment to a 1. Specifying the criteria for all the elements in each range was challenging but helped the consistency of the grading process.

The laboratory report rubric was used to evaluate three types of reports: full reports, summary reports, and test reports. Since each report has different elements the value assessed for each of the categories in the rubric was multiplied by a weight. For example sample calculations were given a weight of 2 on a full report and 0 on sample and test reports since they are not needed in test reports. Also the objective statement was given a weight of 3 in the full and test reports and a 5 in the summary report, because in a summary report the objective statement is of larger importance is such a short report.

The use of four ranges in each category resulted in lower grades than if we had not used rubrics. Because of the explicit criteria in the description of each range, we had to give a 2 or 1 if certain elements were missing from a category. This immediately reduced the grade for that element to 66% and 33% respectively. This is a larger reduction than we would have given without the rubric guideline.

Student feedback was gathered through summative surveys. Also throughout the semester informal discussions with students provided useful information. There were thirteen questions for which the students were asked to provide feedback. The students were asked to assign a numerical value from one to five corresponding to the following qualitative categories, respectively: strongly disagree, disagree, no opinion, agree, strongly agree. The results from the thirty-four sophomore responses are shown in Table 1. The questions are found in the first column. The percentages of responses are found in the next three columns. Note that the strongly disagree and agree responses are pooled, as are the agree and strongly agree responses. The remaining two columns contain the average of the responses and the corresponding standard deviations.

As one can see by examining the data in Table 1, the class tended to have mixed reactions to the rubrics. The averages are all towards the middle. In fact, although the two extreme categories on either side were merged for the table, students more often selected either agree or disagree rather than the more strongly worded option. At the end of the survey students were asked if they had previous experience with rubrics, and there was no statistically significant difference in how students answered the questions depending on whether they had previous experience with rubrics or not.

Survey Question	Strongly Disagree/ Disagree	No Opinion	Agree/ Strongly Agree	Average	Std. Dev.
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The rubrics helped me understand how to present my work in an organized and professional manner	35%	9%	56%	3.2	1.09
The rubrics used helped me to understand what the instructor expected of my work	44%	21%	35%	2.8	1.11
Using the rubric provided me with clear criteria in support of the grade I earned. I understood why I received the scores I got	82%	18%	29%	2.7	1.14
Having the rubric ahead of time made a difference in how I prepared my work	15%	21%	59%	3.6	1.01
Having the rubric ahead of time enabled me to create higher quality work	30%	24%	45%	3.1	1.02
The rubrics made the grading more consistent	38%	12%	50%	3.1	1.20
The rubrics made the grading more fair and equitable	38%	29%	32%	2.9	1.12
Rubrics should be used more often in evaluating course materials	32%	44%	24%	2.9	1.09
Rubrics should be used throughout the entire curriculum (from freshman to senior year)	38%	53%	9%	2.6	0.85
Rubrics are useful assessment tools in engineering design courses	18%	38%	39%	3.2	0.92
Changes to the rubric during the semester should be made to reflect the growth in my ability	15%	24%	62%	3.6	1.04
Any changes to the rubric during the semester should be explicitly discussed in class before the new version is used to evaluate me.	26%	24%	50%	3.4	1.10

Table 1 Survey Results of Laboratory Course (Sophomores, n=34)

Students were also allowed to make written comments following these questions. Fourteen of the thirty-three chose to elaborate on their responses via written comments. These tended to be more negative than positive in nature, which wasn't surprising since students are more apt to express negative comments. These comments focused largely into four main categories: grading, examples, instructions, and learning. There were significantly more comments regarding the grading. Students tended to view the rubrics as a checklist for their reports that was used to punish them. Most of the comments reflected a perspective that is very performance-oriented. The students wanted more examples of what they should do rather than the guidelines put forth in the rubric that attempted to guide them in the direction of how to do something. Some of the comments expressed the notion that the student believed they had met the criteria in the rubric, but still received poor grades. These students often failed to appreciate that they got poor grades because their reports were poor. The students also tended to express a dependency on more instructions on how to use the rubrics and more examples of what the criteria meant. The

instructors were hesitant to provide examples, since the instructors have seen students copy the example and not attempt to reach higher level thinking required to produce original work.

Changes to the Laboratory Course Rubric After One Semester

After using each of the rubrics several changes were made. The changes were not introduced until the next semester. Many of the changes focused the grading on elements that did not receive appropriate attention with the first rubric. For example on the laboratory notebook rubric the emphasis was on the mechanics of the notebook maintenance. Students quickly learned how to satisfy the mechanics requirements, despite poor content. However the first rubric did not allow enough emphasis on evaluating the content. For the next semester categories C,D, and E were combined into one category and category G, Entry Content, was expanded into four categories: (1) Purpose, (2) Equipment and Procedures, (3) Results and Analysis, and (4) Conclusions and Observations. Similarly, category F, Observations and Conclusions, in the lab report rubric was expanded into two categories, (1) Observations and (2) Conclusions. The two categories emphasized that the observations should be embedded along with the discussion of the results and the conclusions are restated in a summary format at the end of the report.

In the laboratory course the students expressed confusion with the weighting system for the different laboratory reports and in general were not able to use the rubrics to understand the expectations for the reports. Several students who expressed this confusion also stated that they had not previously written technical reports. Further, the students did not say that the laboratory notebook and oral presentation rubrics were more helpful even though weights were not used and the rubrics could be used directly for all cases of each material. Therefore, it appears that students need experience with the material being graded by a rubric before they can use a rubric to understand the instructor's expectations while completing an assignment.

The written comments in the student's final course evaluation appeared to emphasize that the students lacked experience writing reports, maintaining lab notebooks, and giving oral presentations. Therefore, the concerns can be addressed with example reports or a checklist. The faculty working in the course decided that for grading, a single rubric with weights was preferred, and ultimately it would be good for students to learn that there are general requirements for technical reports. Therefore for a trial semester, the rubric with a weighting system will continue to be used while the checklist and sample reports will also be implemented. The issues we hope to address with the sample reports and checklists will be assessed at the completion of the semester.

Rubrics in engineering senior design

Rubrics were also designed for evaluating senior-level engineering design reports in the Aerospace Design Methods, AerE 461, and Aerospace Design, AerE 462, the capstone design course. Care was taken in developing these rubrics so that they were consistent with the criteria and standards used by engineering design professionals.

The design report rubric was organized into major skills and performance areas. The students were evaluated on the demonstration of the correct process for problem formulation and design

through their communication of their processes within their report. Criteria within this classification dealt with things like problem definition, requirements analysis, design feasibility analysis, function analysis, and concept development. The second major classification area concerned the actual format and mechanics of writing such as grammar, organization, and appropriateness. Finally, the students were evaluated using criteria that supported the demonstration of how well the student demonstrated the utilization of engineering skills like research, analysis, statement of assumptions, and design thinking.

Students were given the report rubrics before their reports were due. Thus, they had an opportunity to use them as a guide in producing their written reports. Students were asked to evaluate their own work using the same rubric that the instructor used. In many instances, the student's self-evaluation of their work tended to be more negative than the instructor's evaluation. Students were seldom surprised or confused by the grade they received from the instructor. During subsequent discussions, it became clear that these students did use the rubric to guide them in how to document their design work in a technical document. These students, who are at a higher maturity level than the sophomore students, were much more focused on the learning experience than the grading. The seniors did not request examples or even much instruction about the use of the rubric. Very few asked questions about it.

During the first use of the design report rubric, the instructor noticed that the assignments of grades were consistent with the quality of work. In other words, the A-quality work got an A grade. However, the best reports did not get the best numerical grade. Thus, the rubric, including the weighting system, needed some refinement. The categories, criteria, and weighting were all closely examined and some modifications to the criteria were made before the rubric was used in the next semester.

Use of the design report rubric made the grading process more effective and efficient, so much so that a teaching assistant was able to successfully take over grading responsibilities for the course. Students became very comfortable with the use of rubrics and began asking for them for every assignment. Thus, additional rubrics were developed to evaluate teamwork and final presentations.

Student feedback was also gathered through summative surveys and a focus group discussion. The seniors responded to a survey with the same first eleven questions given to the sophomore laboratory course. The senior responses, found in Table 2. Except for one positive comment, the seniors also failed to provide any written comments. This is consistent with the situation where students have a positive experience in a course. Figure 1 shows a graphical comparison of the average responses for the sophomores and seniors. The seniors were much more positive than their sophomore counterpart at a statistically significant level ($p < 0.010$) for all questions except number 8 and 9. As mentioned in the discussion of the sophomore class, this difference is hypothesized to be because the seniors have developed some expertise in the elements being graded so that the direction given by the rubric was easily translated into their actions.

The seniors were also required to give a ten-minute final oral report of their design solution to their peers and several instructors. A separate oral report rubric was developed and given to the students ahead of time. In fact, the students requested the rubric long in advance of the

assignment prior to being aware of its existence. This seems to indicate that they valued the guidance the rubric system provides. The instructors who attended the final presentations used the rubrics and the scores were averaged. It was interesting to note that there were no cases where the results were contradictory. The grading of the oral reports by different instructors was very consistent.

All in all, the implementation of rubrics has been a positive experience for faculty member, teaching assistant, and senior design students. It has transformed the difficult task of grading subject student work into a more efficient and rewarding process for all parties.

Survey Question	Strongly Disagree/ Disagree	No Opinion	Agree/ Strongly Agree	Average	Std. Dev.
1) The rubrics helped me understand how to present my work in an organized and professional manner	0	0	100%	4.3	0.47
2) The rubrics used helped me to understand what the instructor expected of my work	0	0	100%	4.6	0.50
3) Using the rubric provided me with clear criteria in support of the grade I earned. I understood why I received the scores I got	0	0	100%	4.4	0.50
4) Having the rubric ahead of time made a difference in how I prepared my work	0	0	100%	4.7	0.47
5) Having the rubric ahead of time enabled me to create higher quality work	0	45%	55%	3.8	0.87
6) The rubrics made the grading more consistent	0	0	100%	4.2	0.40
7) The rubrics made the grading more fair and equitable	0	18%	82%	3.9	0.54
8) Rubrics should be used more often in evaluating course materials	0	27%	73%	3.8	0.60
9) Rubrics should be used throughout the entire curriculum (from freshman to senior year)	0	55%	45%	3.5	0.69
10) Rubrics are useful assessment tools in engineering design courses	0	0	100%	4.4	0.50

Table 2 Survey Results from the design course (Seniors, n=11)

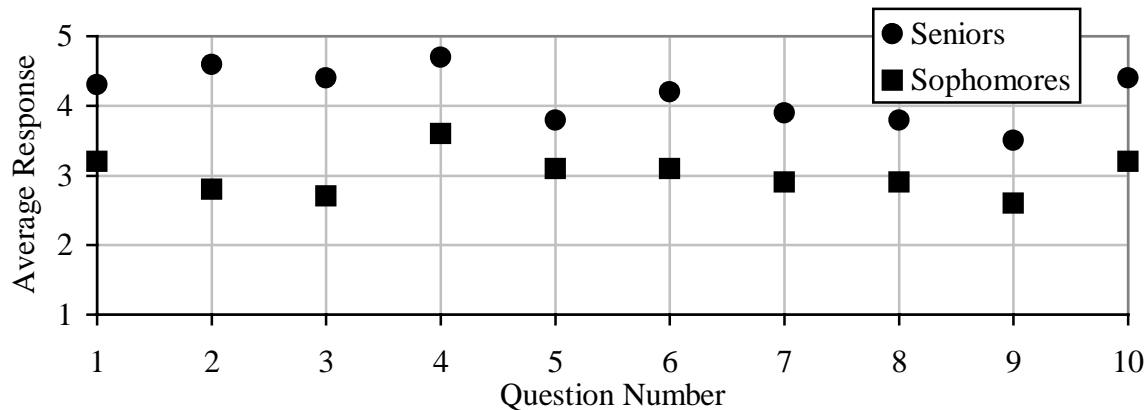


Figure 1 Comparison of the average response from the sophomore and senior classes. The question number is given in Table 2. (1 is strongly disagree and 5 is strongly agree.)

Lessons learned

The faculty who were involved in the development and implementation reported the following observations about their experience.

- One of the keys to success (or failure) of rubrics in the sophomore course seems to be related to the manner in which they were implemented and how well the students were educated about how to use the rubrics. The instructors reported that they believe that the sophomores require more guidance and discussion about the rubric. The seniors in this study were not as dependent on outside guidance.
- Another key to the success of the rubric is the experience that the students have with the material. For students with little experience with an assignment such as technical reports, material such as sample reports or checklists are needed to supplement the rubric as a tool for students to understand what is expected with an assignment.
- Assignments graded with a rubric typically had a larger spread in grades than assignments graded without a rubric. This appeared to be caused by the instructor being forced to apply a predetermined standard with a rubric. It was easier as a grader to give a low grade on an element of an assignment when it was clear what the standard was. One result of the grading was that the students had set standards to work toward which resulted in better reports by the end of the semester than semesters without rubrics.
- The faculty changed the weighting of the objectives as the semester progressed to emphasize the higher-level skills and quality of content as the semester proceeded and the students mastered the mechanical aspects of reporting technical information. The students seemed to find weighting of various objectives to be confusing.
- Instructor collaboration during the development and implementation of rubrics appear to be important to the standardization of the grading. In the case of the design course, the instructor and the teaching assistant discussed the rubrics including the rationale behind the objectives and criteria. The teaching assistant was also given examples of reports evaluated using the rubrics. These efforts seemed to be important in the relative success of using rubrics to standardize the grading. In the laboratory course these steps were not

taken and the student had many complaints about consistent grading with different instructors using the rubrics.

- The design students appeared to pay more attention to the criteria in the rubric when they were given the rubric well in advance of the assignment and asked to use the rubric to evaluate their own work prior to handing in the assignment.
- Students in the design course were allowed to specify their own categories and criteria as part of their final report rubric. This flexibility was provided to account for the diversity in the design projects. Students often included additional information or work that was above and beyond the expectations of the assignment. They were allowed to present their criteria and evaluate their extra work for up to an extra five-percent of their score.
- Once students become comfortable with rubrics, they can provide valuable feedback in the rubric refinement process. The students in each of the courses provided ample feedback and opinions, some of which were very useful to the refinement process. For example, it became especially clear, that the lower-division students needed extra support and detail in the rubric.
- Comprehensive and well-written rubrics can help the students understand the professional standards under which their future work as practicing engineers will be evaluated. The seniors were able to raise their appreciation of professional work and produce report documentation at that caliber. In a junior-level course where the laboratory report rubric was used, the students were quickly able to develop good technical report writing skills. What had passed as adequate work prior to the rigor enforced by the rubrics, was now identified as poor quality. Thus, the rubric raised the bar on the quality of the reports in this class. The sophomores, however, still appear to need extra detail and support as they develop their reporting skills. The refinements and support materials developed for these lower-division students will be implemented during the spring semester and tracked. The results will be analyzed and subsequently disseminated.

For those who are interested in learning more about the rubrics used for either the laboratory or design courses, please contact the authors.

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