Using Rubrics to Facilitate Students' Development of Problem Solving Skills

Kevin P. Saunders[1], Charles E. Glatz[2], Mary E. Huba[1], Maureen H. Griffin[3], Surya K. Mallapragada[2], and Jacqueline V. Shanks[2]

[1]Iowa State University Department of Educational Leadership and Policy Studies/ [2]Iowa State University Department of Chemical Engineering/ [3]Des Moines East High School

Abstract

We developed a series of problem-based laboratories in chemical engineering designed to engage students as active participants in their own learning. The goals of the problem-based learning (PBL) format include helping students develop problem-solving skills, improving students' own understanding of how they learn, developing a life-long learning perspective, and acquiring the ability to work on interdisciplinary teams. To assist students and faculty in assessing these learning objectives, we developed rubrics to assess teamwork, written and oral reports, and the problem-solving process. In this paper we describe the implementation of PBL in engineering curricula and examine the use of rubrics to support the development of students' problem-solving skills.

Introduction

In the chemical industry of the future, chemical engineers will be increasingly expected to use their process and design skills in the manufacture of bio-based industrial products. Although many chemical engineering curricula today include a senior-level biochemical engineering course, additional course materials that incorporate biotechnology principles will be needed in the future.

The central element of our undertaking was to involve students in solving laboratory-based problems related to the conversion of biorenewables. Using a problem-based learning (PBL) approach, we grouped students in multidisciplinary teams, assigned them a problem from industry, and guided them through the steps of a problem-solving process, i.e., recognize the relevant knowledge they already possess, identify what must be learned, acquire that knowledge and work towards a solution.

PBL originated in the 1960s and 1970s when medical educators tried to find a better means of preparing physicians for medical practice [1]. They decided to educate students by having them solve typical problems encountered in professional practice, an approach that provides opportunities for students to practice life-long learning and team skills. PBL is now widely practiced in medical schools and has been applied to a lesser degree in other disciplines.

We believe that PBL can be effectively implemented in engineering curricula. The Accreditation Board for Engineering and Technology (ABET) considers the following to be among the 11 required outcomes attained by engineering graduates [2]: ability to engage in life-long learning; ability to work in multidisciplinary teams; ability to identify, formulate and solve engineering problems; and ability to consider the ethical and social dimensions of engineering solutions. These outcomes are those that prove most difficult for engineering faculty to achieve in the standard curriculum. Our approach is to combine improvement in these ABET-related process skills with the learning of critical technologies for producing value-added products from biorenewables.

Barrow [3] outlines the key features of PBL. The learning is student-centered and carried out in small groups with the teacher as guide. Problems provide a focus and motivation for learning, developing problem-solving skills is a desired component, and students identify the need for new information and then obtain it. In addition to the technical knowledge acquired by motivated learners, the outcomes include skills for problem solving, teamwork and life-long learning. PBL helps students know when and how to use knowledge, offers students the opportunity to demonstrate unique abilities, and allows students to work in teams [4].

Additional recommendations for effective use of PBL are available in the literature. For example, Allen et al. [5] point out the need to acquaint the students with the learning resources available to them ahead of time and explicitly identify attributes for successful teamwork. Woods et al. [6] recommend that students be consciously involved in developing desired process skills. Students need to be made aware of the benefits of the course beyond factual knowledge. They need to be informed about how their learning will occur so that they can develop the metacognitive ability to assess their own progress. Self-assessment results from reflecting on questions such as, What am I going to do? How do I do it? Did it work? (See additional recommendations at the web site http://chemeng.mcmaster.ca, as well as that of Richard Felder, http://www2.ncsu.edu/effective_teaching/).

PBL also provides opportunities for faculty to identify learning goals that reflect important disciplinary skills, abilities, and perspectives, as well as ways to assess them authentically. Huba and Freed [4] explain that authentic or real-world assessments support students' motivation to learn and promote their development as learners.

The rubric is an example of an assessment tool that can be useful in assessing the important outcomes of PBL. A rubric is a public description of the criteria that distinguish good work from poor work, and it can be used to both promote and evaluate student learning in the area of a particular learning outcome (Huba and Freed [4]). According to Huba and Freed, rubrics assist students by offering clear criteria that can guide students in the development, revision, and evaluation of their own work, a process that is particularly useful when solving open-ended problems in the PBL environment. In this paper, we describe how we developed rubrics as means of consciously involving students in the learning process.

Our overall project includes four laboratory-linked modules. Each has a list of desired technical outcomes that should result from the solution of the problems that are assigned, as well

as a set of process-related outcomes. The instructors do not initially share the technical outcomes with the students. Rather, the instructor uses them to develop questions that can be raised with students during the problem solving process, guiding students in new directions as they develop and test solutions. The process outcomes are shared with students at the outset, along with rubrics describing the essential components of each of the outcomes. The following results section first describes the desired subject-related outcomes for each individual laboratory course. Next, we describe the development of rubrics for the process-related outcomes and the results of implementing these rubrics in the laboratory courses.

Results: Subject-related student accomplishments

Three of the four modules have now been taught. The subject coverage of each is described briefly as follows:

The metabolic engineering laboratory module combined experimentation with mathematical analysis of the metabolism of the ethanol fermentation. Extracellular measurements of product and substrate levels of the fermentation broth were the input to a metabolic model that consisted of stoichiometric equations. The outputs of the analysis were the calculated metabolic fluxes. Students in this course will be able to perform a yeast fermentation, model the network for ethanol formation, determine and carry out the measurements needed, analyze the flux distribution, assess areas of reaction network for genetic modification, and determine whether more tools are needed for future characterization.

The plant protein recovery module allowed for exploration of alternative separation sequences for recovery of a recombinant protein from transgenic corn. The research aspect was enlivened by the result being sent to the company planning to commercialize the process. The resulting student-selected experimental effort included selective extraction, precipitation, ultrafiltration, ion exchange and hydrophobic interaction chromatography for purification of the protein product from the corn extract. The project provided opportunities to consider both process (column operation) and product development (resin selection) questions. Students in this course will be able to collect and store samples, prepare and standardize solutions, be able to perform the procedures listed above, interpret and report results, and draw appropriate conclusions regarding procedures and results.

The module of development of materials for skin tissue propagation exposed students to biotechnology-related product development through an experiment involving skin tissue culture on porous biodegradable polymer scaffolds. The students explored the use of various polymer substrates for skin culture in bioreactors. This enabled them to use chemical engineering principles to determine the appropriate media flowrates and control the heat and mass transfer rates to provide the right environment for the cells. The extended application was to design an appropriate bioreactor to sustain the growth of the cells on the polymer substrates for a period of two to three weeks to form artificial skin with good transport of nutrients and wastes to and from the cells. Students in this course will obtain an overview of polymer science and engineering, be able to identify the criteria to be satisfied before choosing a polymeric biomaterial, know necessary tests to assess biocompatibility, be able to recognize important properties of polymers with respect to

biocompatibility, and understand bioethical issues associated with the use of biomaterials.

Results: Problem-solving student accomplishments

Each of the three modules shared common problem-solving course learning outcomes. Through these courses, students develop problem solutions using information from several information sources, function effectively on multidisciplinary teams, express ideas effectively orally and in writing, plan and monitor progress, improve self-knowledge of how they learn, and self-assess their role in developing an effective solution.

Rubric development and implementation. The term began with an orientation session that helped students learn about or review topics such as problem-based learning, research methods, statistical analysis, research ethics, literature searching, and lab safety. We also familiarized them with two key elements of the module: (1) the rubrics we would be using to assess each process outcome (written and oral communication, weekly reports, teamwork, and problem-solving) and (2) the web-based tools we would employ to deliver materials, administer surveys, and communicate with the class. In several of the laboratory courses, faculty discussed the rubrics with students and gave them the opportunity to revise and clarify the rubrics.

Before describing each of the rubrics, it is important to discuss the following elements of a useful rubric: levels of mastery, dimensions of quality, organizational groupings, and commentary [4]. Each of the rubrics contains these important elements. First, across the top of the rubrics are categories that indicate various levels of mastery, such as exemplary, proficient, marginal, and unacceptable. These levels of mastery allow faculty and students to identify the level of students' learning. Second, in the first column of the rubrics entitled "criteria," are the key dimensions of the learning outcome that have been found to distinguish good work from poor work. Third, in the teamwork and problem-solving rubrics, these criteria are organized into themes to provide an overall framework for related items. This allows students and faculty to understand how the components of the learning outcome are related to each other. Lastly, each cell contains a detailed commentary that explains the different levels of mastery for each dimension of quality. Students and faculty can use this information to both understand expectations for learning and to assess progress.

The written and oral rubrics (Figures 1 and 2) have evolved from an initial set of categories suggested by Rebecca Burnett of Iowa State, with most of the actual performance indicators written by Bonita Glatz of Iowa State, with minor editing to adapt them to our modules by C. Glatz who had used them in previous courses. The use of these rubrics varied among the courses. In one case, the instructor asked students to evaluate each other's presentations throughout the semester. In another course, the teaching assistant and instructor used the rubrics to evaluate each team's final report.

Because progress reports are an integral component of the courses and are critical to ensuring that students make timely progress and effective use of tutors, an additional "progress report" rubric has been developed as shown in Figure 3; however, this has not been available for use in the modules taught thus far.

We adapted the rubric for teamwork (Figure 4) from an existing rubric developed by Jiles et al. [7]. It has been used in the modules to date and was introduced in the teamwork training session common to all modules. During the PBL process, student teams fill out a consensus rating of their team's performance during the term, and students individually rate their own teams. In one course, students completed the individual rating of teamwork at the end of the term, while in other courses students completed the individual rating of teamwork several times throughout the term. The final evaluation also requires the students to specify the contribution of each team member to the team's success.

The rubric for problem-solving (Figure 5) draws upon previous research on PBL [6, 8, 9] and details the steps of the problem-solving process. We designed it to help students reflect on the development of their problem-solving skills. Students and instructors used this rubric to assess overall learning at the end of the semester.

Evaluation of PBL and Rubrics. The use of rubrics for faculty and student evaluation of learning is different from traditional assessment methods. The implementation of the PBL format is a shift to a learner-centered approach that requires changes in the traditional laboratory structure and format. Huba and Freed [4] explain that one strategy to support students through these changes is making evaluation standards public through tools such as rubrics in order to facilitate a trusting relationship between faculty and students. Another strategy is to ask students for feedback that faculty can use to improve the learning environment. We sought this type of feedback by asking students throughout the term to provide reactions to various aspects of the course through written journals and focus groups. Analysis of these comments provided information regarding the benefits and challenges of both rubrics and the PBL learning environment in general.

Students described several benefits of using rubrics in the PBL laboratory courses.

- Rubrics helped them understand learning outcomes that are different from those in courses that do not use a problem-based learning format. Due to the change in the learning environment, rubrics offered one way to help students develop identified process skills and to gain confidence in a new approach to learning.
- Students could use the rubrics to promote self-directed learning. Students explained that the faculty member served as a facilitator and had limited direct contact with the students. Several student groups explained that they did not expect the course to be as self-guided as it was, but they agreed that this was a positive learning format. One group explained how the communication rubrics helped them prepare for meetings, causing them to anticipate problems and ask critical questions.
- Rubrics helped students keep on track, break down the project, and document progress. Although students received the rubrics at the start of the semester, they progressed in their ability to use the rubrics as effective learning tools. Because students are unfamiliar with the different curriculum and the use of rubrics, it is important for facilitators to emphasize the value of these tools and to remind students of their purpose throughout the semester.

Students also shared the challenges of the PBL format and the use of rubrics.

- Several student teams suggested that the courses should be more structured with specific aims and goals. These comments illustrated that students are not familiar with the use of rubrics and are not accustomed to using them for guidance or structure. Several students requested a structured timeline and a specific problem with identified tasks. In other words, at times students wanted to be "told what to do."
- Several groups of students explained that they were not sure whether the goal for the course was to successfully solve the problem or to develop thinking and communication skills (i.e., teamwork, written and oral communication, and problem-solving skills). Students explained that they were uncertain of the nature of the project, and they reported that it would be helpful to periodically revisit the goals and objectives of the course.
- Students were uncertain how the rubrics related to assessment of student performance. Part of students' negative reaction to rubrics seemed to be related to students' concerns about how instructors would use the information to assign grades rather than recognition of how rubrics can help students evaluate what they have learned. Students were unsure how of how the instructor would use the rubrics and how much emphasis was on content knowledge compared to process skills.
- Students in some groups explained that they did not regularly use the rubrics throughout the semester, which made the purpose and value of the rubrics unclear. Another group stated that the general expectations (commentary) were not helpful and that the students would like additional details about each point.

Discussion

Students' comments regarding the benefits of rubrics suggests that this tool is helpful in helping students understand course-specific learning outcomes. This seems especially important when the learning environment is unfamiliar, as was the case in these PBL laboratories. We found that it is important to involve students in revising and finalizing the rubrics, thereby assisting them in setting standards as well as meeting them. A discussion about the characteristics of the excellent work they are encouraged to achieve facilitates a trusting relationship between teachers and learners, but more importantly encourages students to become more involved and purposeful regarding the learning experiences they hope to achieve. Ongoing conversations between faculty and students about learning can help to address many of the concerns that students share (e.g., unclear goals, vague course structure, and uncertainty of performance assessment) by clarifying the intended learning outcomes and involving students in defining the best ways to accomplish these outcomes.

Rubrics allow students to learn in new ways and can improve communication between faculty and students. In this project, we saw examples of students using rubrics to evaluate the quality of their work and to anticipate possible questions from the instructor. Faculty can use the rubrics to provide immediate feedback in an effort to guide students' early work. When both instructors and students complete rubrics to evaluate the quality of learning efforts throughout the semester, students develop in their understanding of their strengths and achievements, weaknesses, and progress. It may be helpful, therefore, to use each rubric throughout the semester as both a communication and an evaluation tool. For example, in future courses we may use the problem-solving rubric throughout the semester, rather than only at the end of the semester,

allowing students and faculty to explore students' on-going development of problem-solving skills.

Through the PBL format and the use of rubrics, students had the opportunity to learn from one another. We asked students to provide feedback to other students regarding their performance. For example, students completed the teamwork rubric both individually and as team, allowing students to discuss difficulties, set common expectations, and examine group dynamics. In another example, student teams from the PBL laboratory course presented information in a corresponding lecture course. Students in the lecture course evaluated the team presentations using the oral presentation rubrics. Future research efforts might explore the following questions: how did students use the team feedback/peer evaluation or what did individual students learn through the experience?

Rubrics can help students form and adapt lifetime standards for assessing performance. Several students indicated that they improved in their ability to document progress, critically evaluate communication, and reflect on learning. Rubrics help to inform students of quality benchmarks that they can use to evaluate work in progress. While rubrics represent an effective assessment and feedback tool, having students assess their own work before submission with these benchmarks helps students to identify ways to improve the quality of their efforts. Several faculty members decided to implement the written and oral rubrics in lecture courses associated with the PBL laboratory courses to encourage other students to evaluate their efforts.

PBL represents an atypical learning environment which offers challenges to both students and faculty as they engage in different ways of learning. We designed the course rubrics to assist both students and faculty in making the transition to the new environment, and we found that the rubrics were generally useful and favorable received by the students. Nevertheless, some students described several challenges of using rubrics in the courses, and struggled with the open-ended nature of the PBL format. Students' concerns suggest that we need to build upon our successes and continue to explore ways to incorporate the use of rubrics even more deliberately into the course environment.

This paper presents several rubrics and their use in the context of a PBL environment. Each of the rubrics, with the exception of the Problem-Solving Rubric, are appropriate for other course settings that require team assignments or written and oral reports.

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Biographical Information

KEVIN P. SAUNDERS is a doctoral student in Educational Leadership and Policy Studies at Iowa State University.

CHARLES E. GLATZ is Professor and Chair of Chemical Engineering at Iowa State University. He earned his doctorate in chemical engineering at the University of Wisconsin.

MARY E. HUBA is the Assistant Vice Provost for Undergraduate Programs and Professor of Educational Leadership and Policy Studies at Iowa State University. Huba provides leadership for outcomes assessment at Iowa State. She earned her doctorate in educational psychology at the State University of New York at Albany.

MAUREEN H. GRIFFIN is a general and advanced chemistry teacher at East High School in Des Moines, Iowa. She earned teacher of the year awards in 2000 and 2001 at East High School.

SURYA K. MALLAPRAGADA is Associate Professor of Chemical Engineering and Materials Science and Engineering at Iowa State University. In 2002, she was named by MIT's Technology Review as one of "Top 100

Young Innovators." She earned her doctorate in chemical engineering at Purdue University.

JACQUELINE V. SHANKS is Professor Chemical Engineering at Iowa State University and Adjunct Professor of Bioengineering at Rice University. She earned her doctorate in chemical engineering at the California Institute of Technology.

Figure 1. Written Report Rubric

Criteria	Excellent (A) 4	Good (B) 3	Fair (C) 2	Poor (D) 1
Abstract or Executive Summary	Summarizes goal of project and results concisely. Specific information provided.	Most information is presented, but some items may be missing.	Insufficient summary of what was done. Few specific results presented.	Abstract is missing or contains no specific information.
Introduction	Discusses why the study was done, and expected behavior. Presents background information, with references, relevant to the study.	Gives general description of the purpose of the study, but some relevant background information may be missing.	Some information on the purpose of the study is given, but no background or references provided.	Provides little or no information on why the study was done. No background information given.
Materials and Methods (or Calculations)	Concisely describes methods or gives references to sources of methods used. Assumptions well described.	Methods generally are well described or referenced, but some items may be insufficiently described or left out.	Methods may be insufficiently explained, or may be described in too much detail. Large gaps in information.	Most key pieces of information are missing. References to methods aren't provided.
Results	Data are presented in one or more tables, with accompanying text to introduce the tables. Figures are used to illustrate key comparisons or trends. No errors in calculations.	Data tables are presented, but some calculations may be in error, some data may be missing, or figures may be insufficient.	Insufficient data are presented, or several errors in calculations are present and distract from the results. Text and/or figures may be missing.	Raw data are missing. Reported counts are calculated incorrectly. No text to present the results. No figures or alternative methods of data presentation.
Discussion	Clearly discusses what results mean and what conclusions may be drawn from them. Cites published standards or other related reports.	Generally clear discussion of results and conclusions, but may miss some points. Some use of references and published standards.	Limited discussion of results and conclusions. Little or no reference to published standards or other reports.	Reader can gain very little information about why the project was done and what the results may mean. No reference to other studies.

Figure 1 (continued). Written Report Rubric

Criteria	Excellent (A) 4	Good (B) 3	Fair (C) 2	Poor (D) 1
References	Includes references to methods, related studies, background sources within text; list of complete citations in appropriate style at end.	Appropriate references are generally present; some may be incomplete or in incorrect style.	Few references are given. Style is incorrect and/or incomplete.	No references provided.
Style (detailed calculations in appendices)	Writing is free of errors in grammar, punctuation, capitalization, spelling. Uses active voice. Flows smoothly. Logical connection of points. Follows standard organizational style.	Writing is generally error-free and in active voice. Sentence flow is generally smooth and logical. Standard style is generally followed. Minor errors may be present.	Writing has some errors but these are not too distracting. Voice may change randomly. Flow is not consistently smooth; appears disjointed. Style is not followed consistently.	Errors are frequent and distracting, so that it is hard to determine meaning. No logical connection of ideas or flow of sentences. Journal paper style is not followed.

Figure 2. Oral Report Rubric

Criteria	Excellent (A) 4	Good (B) 3	Fair (C) 2	Poor (D) 1
Organization	Presentation is clear and logical. Listener can easily follow line of reasoning.	Presentation is generally clear. A few minor points may be confusing.	Listener can follow presentation with effort. Organization not well thought out.	Presentation is very confused and unclear. Listeners cannot follow it.
Style	Level is appropriate for presentation of engineering results. Not too casual. Speakers are easy to hear and understand.	Level is generally appropriate. May have some trouble in hearing or understanding a speaker.	Presentation is too informal or unprepared. Difficult to hear or understand speakers. Much of information is read.	Presentation is consistently at an inappropriate level. Information is read. Speakers can't be heard or understood.
Pace	Presentation is a planned conversation, paced for audience understanding.	One speaker's pacing is too fast or too slow, repetitive or skipping important details.	More than one speaker is too fast or too slow, repetitive or skipping important details.	Presentation is far too long or far too short. Speakers generally are too fast or too slow.
Content: Depth	Design, methods, results, conclusions are clearly stated. Implications of results and "where do we go from here" discussed.	Description of project and results is generally clear. Some discussion of what results mean.	Some components of project description are minimal or missing. Little discussion of what results mean.	Description of project and results is very difficult to follow. No discussion of meaning of results. Listeners learn little.
Content: Accuracy	Information given is consistently accurate. Facts and calculations are correct.	No significant errors are made. Listeners recognize errors as result of oversight or nervousness.	Enough errors made to be distracting, but some information is accurate.	Information is so inaccurate that listener cannot depend on the presentation.
Use of Visual Aids	Aids prepared in professional manner. Font is large enough to be seen by all. Well organized. Main points stand out.	Aids contribute, but not all material supported by aids. Font size is appropriate for reading.	Aids are poorly prepared or used inappropriately. Font is too small. Too much information is included.	No aids are used, or they are so poorly prepared that they detract from the presentation.
Responsiveness to Audience	Responds well to questions. Restates and summarizes when needed.	Generally responsive to questions.	Reluctantly interacts with audience. Responds poorly to questions.	Avoids audience interaction. Not responsive to group.

Figure 3. Rubric for Weekly Written Reports/Documentation

Criteria	Exceeds Expectations	Meets Expectations	Needs Improvement
Documentation	The team provides written documentation that clarifies their experimental results for that week. Objectives for the past week are clearly stated in relation to project goals, and the report is structured around their accomplishment.	Written documentation is generally complete, but occasional omissions create some lack of clarity. Objectives for the past week are included with no relationship to project goals.	There is no supporting written documentation.
Organizing and Managing	Is well organized, with project tasks and objectives clearly specified and with work progressing regularly and methodically.	Demonstrates an organized approach with regular work habits	Work appears to be performed at odd hours and during infrequent spurts of activity.
Detailed Description of Important Elements of Progress	Report contains statements about activity highlights, including but not limited to: • Activities • Experimental results • Explanation of results • Reasons for discrepancies between what was planned and what occurred.	Report contains description of activities, results and/or explanations.	Report does not contain results or explanations for lack of results.
Graphs and Charts	Graphs and charts are used to support the description of progress where appropriate. These are labeled and organized so it is easy for the reader to follow.	Graphs and charts are used where appropriate.	Graphs or charts are not utilized where they would clearly be desirable to emphasize or clarify results.
Organization	Items are organized in a logical progression.	Items are organized and ordered in some more or less helpful way.	Items are in illogical or poorly considered order, or in no order.

Figure 3 (continued). Rubric for Weekly Written Reports/Documentation

Criteria	Exceeds Expectations	Meets Expectations	Needs Improvement
Punctuality	Reports are consistently submitted on time.	Reports are usually submitted on time.	Reports are rarely submitted on time.
Plans for Next Step	Planned activities for the next week are listed, showing understanding of what must be done to continue the project. Alternative ideas are included that demonstrate foresight about potential problems.	Report gives indication of what steps come next. Demonstrates some understanding of possible problems but offers no alternate ideas.	No attention given to next weeks plan.
Summary statement	A clear summary of the main activities is included with quantitative and/or qualitative information, so that the reader can quickly determine the rate of progress.	A summary of main activities is included.	No summary is provided.

Figure 4. Teamwork Rubric[1]

Criteria	Exemplary	Satisfactory	Unacceptable
Group Functioning			
Attending	Most, if not all, members attend all meetings.	Most members are present at most meetings. When members have to be absent, they inform and/or seek the agreement of the team.	Many members frequently miss meetings and do not inform the team.
Participating	There is a clear definition of tasks to be accomplished, anticipating future needs. All members take an active role. Tasks are defined by the group and assigned to all members. The team engages in follow-up activities to monitor progress.	Tasks are defined informally, and most but not all members understand them. Most members contribute. Follow-up is sporadic.	Tasks are not defined, and few members participate actively. There is no follow-up.
Defining Members' Roles	Every member's role on the team is defined and understood by all. Each team member can explain the role of others.	Members' roles are defined informally and may not be completely understood by all. Some members may not be able to explain the role of others.	There is little understanding of who does what.
Making Collective Decisions	Clear procedures for making decisions are established and documented. Decisions, the process by which they were made, and the involvement of members are also documented.	Decision-making procedures are established informally, leading to inconsistency in implementation and a failure to involve all members in decision making.	Because there is no decision-making process, decisions are made by individuals, and they do not reflect the thinking or the desires of the team.
Team Member Support	Every team member is treated with respect. All members listen to all ideas. The work of each person is acknowledged. Members feel free to seek assistance from others or to ask questions.	There is a general atmosphere of respect for team members, but some members may not be heard as much as others. Acknowledging others' work is serendipitous rather than planned. Some members may not feel free to turn to others for help.	The team atmosphere is competitive and individualistic rather than cooperative and supportive.

Figure 4 (continued). Teamwork Rubric[1]

Criteria	Exemplary	Satisfactory	Unacceptable
Managing Conflict	Conflicts are consistently resolved through open discussion and compromise.	Members are generally able to resolve conflicts through open discussion and compromise.	Conflicts that arise are either not dealt with or cannot be resolved.
Process Management			
Meeting Regularly	Weekly or biweekly meetings are scheduled and held at defined times.	Meetings are scheduled sporadically to keep the project going.	Meetings are rare.
Establishing and Documenting Goals	Realistic, prioritized, and measurable goals are agreed upon and documented.	Goals are established. but some may be too general or unquantifiable. Priorities may be unrealistic. Documentation may be incomplete.	Clear goals are not formulated or documented.
Keeping Meeting Notes	Written minutes summarize attendance, discussions, and actions. Minutes are distributed electronically within two days of the meeting.	Minutes summarizing attendance, discussions, and actions are written and distributed but not consistently. Some minutes are more complete than others.	Minutes are either nonexistent or sketchy, containing little beyond attendance lists.
Adjusting	When working to achieve goals, the team is able to adjust plans as needs arise. There is a clear understanding of the nature of mid-course corrections and why they were needed.	The team is not always able to adjust as needed to meet goals. Realization of the need for mid-course corrections sometimes comes too late.	The team seems to be thrashing about. Activity plans (if they exist) are unfocused, and thus there is no ability to adjust and make corrections.
Timely Submission of Work Assignments and Reports	Team is self-motivated and can complete work assignments and reports in a timely manner without being reminded.	Work assignments and reports are submitted but are sometimes late.	Work assignments and reports are submitted inconsistently. The team is not self-motivated and needs constant chasing to get the work submitted.

[1]Adapted from Jiles, D., Huba, M., & Others. "Vertically Integrated Design Curriculum," Unpublished Rubric for NSF CRCD Project, Material Sciences and Engineering, Iowa State University (8-24-00).

Figure 5. Problem Solving Rubric

Criteria	Exemplary (4 - 5)	Good (2 – 3)	Needs Improvement (0 – 1)
Identifying Problem and Main Objective			
Initial Questions	Questions are probing and help clarify facts, concepts, and relationships in regard to problem. Follow-up questions are gleaned from the literature.	Formulates questions and determines relevant information to identify the problem in light of the client's needs. All questions may not be relevant. May have some difficulty formulating questions to move toward better understanding of the problem.	Expects others to define the questions. Does not seem to understand client's needs.
Understanding the Problem	Clearly defines the problem the client presents. Outlines necessary objectives in an efficient manner.	Formulates a clear and specific problem statement.	Offers ambiguous definition and interprets problem narrowly.
Seeking Information	Seeks out initial sources of information for problem definition, identifies individuals for support, and formulates learning strategies. Places problem within context of previous knowledge and what is not known about the problem.	Can identify relevant issues regarding problem. Relies on a few sources only. Does not gather extensive information.	Not clear as to what is needed. Waits to be told. Does not seek sources of information.

Figure 5 (continued). Problem Solving Rubric

Criteria	Exemplary (4 - 5)	Good (2 – 3)	Needs Improvement (0 – 1)
Applying Previous Knowledge			
Integration of Knowledge	Applies & integrates previous knowledge to current problem. Able to synthesize information to assist problem solving process.	Identifies theory from previous knowledge of current problems. Does not consistently use theory in an effective manner.	Unable to make connection to earlier courses. Unwilling to review previous courses for potential knowledge.
Sharing Previous Knowledge	Leads other team members in gaining knowledge. Listens respectfully to the opinions of others. Able to assist the team in applying and synthesizing information.	Provides useful knowledge to team members. May not consistently address team members' needs or level of understanding.	Expects others to teach self. Does not share knowledge.
Identifying Information			
Use of Information	Throughout the process, demonstrates ability to gather and use a broad spectrum of resources and information. Integrates information with knowledge and problem-solving strategies.	Identifies and finds resources to help solve problem and can interpret information. May have difficulty using information effectively in problem solving. Does not consistently gather extensive information.	Fails to see relevance of gathering information. Obtains information from limited or inappropriate sources. Expects others to make connections between information gathered and the problem.
Framework	Creates and applies a framework (e.g., a flow diagram, other visual , written description, or mathematical statements) throughout the process. Revises framework as necessary and uses it to aid in problem-solving.	Can create a clear description framework (e.g., a flow diagram, other visual , written description, or mathematical statements) to help formulate a model of the problem. May not be consistently used in an effective manner.	Creates vague/ambiguous frameworks that do not move the problem-solving process along. Doesn't ask for clarification from others.

Figure 5 (continued). Problem Solving Rubric

Criteria	Exemplary (4 - 5)	Good (2 – 3)	Needs Improvement (0 – 1)
Tasks	Demonstrates initiative and leadership in helping the group: • Match assignments to expertise. • Develop strategies to enhance group success. • Rotate responsibilities when appropriate. • Maintain an open communication process regarding team members' findings.	Helps the group prioritize tasks and identify each group member's responsibilities. Cooperates with the group.	Spends time on tasks that interfere with the problem-solving process. Leaves meetings not knowing who is responsible for tasks.
Designing and Conducting Experiments			
Design	Able to develop and describe a planned experiment that relates to problem. Hypotheses clearly relate to previous knowledge. Can identify necessary steps and timeline. Works collaboratively on the development of the project.	Formulates a hypothesis and develops a project, experiment, or series of experiments that will address the problem. Anticipates possible outcomes.	Fails to formulate hypothesis to test. Does not express possible outcomes.
Use of Evidence	Continuously uses results to refine problem-solving plan. Draws correct conclusions from results and generates presentation information (e.g., plots, tables, calculations) that consistently aid understanding of the problem. Explores new ways of doing tasks.	Adjusts experimental plan on basis of new knowledge. Usually plots/tabulates results and performs calculations to aid reaching conclusions.	Does not base conclusions on evidence. Calculations contain errors. Plots use wrong axes.

Figure 5 (continued). Problem Solving Rubric

Criteria	Exemplary (4 - 5)	Good (2 – 3)	Needs Improvement (0 – 1)
Documentation	Documentation is comprehensive and includes detailed instructions that would allow you to repeat the experiment later using only your notes. Extra data sheets are firmly attached and numbered.	Provides organized documentation of experimental results. Data sheets are numbered. (See detailed notebook instructions.)	Fails to maintain an organized laboratory notebook. Unable to locate experimental results due to lack of organization.
Analyzing, Interpreting, and Communicating Results			
Use of Analytic Tools	Demonstrates ability to successfully use new analytical tools and procedures. Can describe the rationale for these processes.	Attempts to use analytical tools (e.g., statistics) in relation to the problem solving process. May not be successful.	Does not evaluate sources of error. No replicates or control experiments are performed.
Interpretation of Data	Relates solution to theory and research. Able to describe conclusions in a clear and concise manner using experimental results and those cited in the literature. Contrasts results with those expected from hypotheses.	Interprets results and draws conclusions based on the data.	States conclusions without justification. "Hopes" the answer is correct. Does not consider internal consistency of results. Does not link cause and effect based on data.
Analyzing alternative Interpretations and Solutions	Proposes limitations and alternative interpretations. Able to account for unexplained results.	Uses information gathered to refine original problem.	Fails to look at solution relative to the original question.
Communicating Results	(See detailed oral and written communication rubrics.)		

Figure 5 (continued). Problem Solving Rubric

Criteria	Exemplary (4 - 5)	Good (2 – 3)	Needs Improvement (0 – 1)
Assessing Self and Others			
Problem Solving Process	Offers clear insights regarding self-knowledge - what has been learned through the problem-solving process.	Critically reflects on problem solving techniques, strategies, and results. Identifies those most helpful to self.	Unable to reveal insights about own learning.
Collaborative Learning	Assists the group in developing strategies for success. Demonstrates an understanding of how problem-solving process relates to other learning activities. Facilitates reflection and learning in self and others. Creates a positive environment for collaborative learning.	Assesses how team members' skills, knowledge, and attitudes contributed to self-directed and collaborative learning and the problem solving process.	Assessments of self and others are not insightful. Shows no commitment to group's development of skills for the future. Inattentive to group morale.
Overall Assessment	Clearly and concisely articulates problem solving process and applies it to current problem.	Understands problem solving process, does not apply to current problem.	Goes through the motions of solving the problem with no real understanding of the process involved.