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A Management/Grading System for Teaching Design in Mechanics of Materials and Other Courses*

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A plan for class management and grading in Mechanics of Materials with design is offered for two reasons: (1) Teaching design in a topic-packed analysis course like Mechanics of Materials places demands upon instructors beyond the traditional course and this paper offers suggestions on how to cope. (2) At Penn State, the Engineering Science and Mechanics Department traditionally seeks a degree of conformity between sections and offers a common final exam, hence there are some rules that instructors must follow to maintain this policy. The paper is the result of experience and treats methods for selecting teams, guiding students through learning the design process, structuring the design report and assigning grades to individuals within a team. The plan is aimed at effective, yet efficient teaching, is open to continuous improvement and applicable to other courses.

SUMMARY OF EDUCATIONAL ASPECTS OF THE PAPER

1. The paper provides management procedures necessary to successfully teach design in an analysis course, offers suggestions on how to select student design teams and assign individual grades to team members and includes examples for design projects.
2. Students in all engineering departments except electrical and computer engineering take this course.
3. The level of this course is usually second-year undergraduate, but management procedures offered here would apply to managing group projects in any undergraduate analysis course.
4. The mode of presentation is typically lecture with demonstrations, but group learning is encouraged both in and out of class.
5. The course is standard for engineering students.
6. The course requires 45 hours total to cover the material; 6 hours concentrate upon design.
7. As a goal, student work outside of class requires 3 hours per hour of lecture.
8. The novel aspect of this paper is its meticulous construction of a management/grading system, which enables teaching design efficiently in an otherwise traditional analysis course.
9. A text which covers both theory and design methods at the comprehensive level treated here is not available, but several on the market include design problems and light coverage of design procedures.

INTRODUCTION

DESIGN CAN BE introduced into an analysis course through simple homework problems supported by light presentation of 'inverted' analysis equations or it can be seriously taught by making room for it in the course syllabus and assigning both simple and substantial open-ended design problems to students. We opt for the latter by including 6 hours (out of a 45–hour course) of focused design instruction, distributing simple design problems throughout the course and assigning a single, open-ended, 9-week, team design project.

There are several reasons for teaching design in an undergraduate analysis course:

1. It opens a broad view of engineering to students through technical standards, materials selection, safety and environmental concerns and economic considerations;
2. It exercises student creativity and other non-analytical talents through a realistic experience which demonstrates one very important application of analysis—hence it motivates learning;
3. It conforms to the contemporary viewpoint that engineering education should include technical breadth, a mix of integrated skills and team project experiences [1].

An overview of teaching design in a related context, yet pertinent here, is given by Dutson, *et al.* [2].

Of course an overriding concern is: 'can design fit into an already topic-packed course without causing fundamental mechanics learning to suffer?' We have demonstrated that the answer is yes and will report on course design and

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assessment of this effort in forthcoming papers. Nonetheless, including design in an analysis course is neither trivial nor impromptu. It requires careful advance planning and disciplined in-class presentation. This paper addresses planning issues as well as grading.

COURSE MANAGEMENT

Team selection

Why assign projects to teams of students rather than individual students? For two reasons: (1) teamwork experience and group learning is strongly suggested by contemporary educators to alleviate strict lectures [3] and (2) in large classes team-generated projects reduce the number of reports an instructor has to grade to a tractable amount.

Rule 1. Design projects will be done by teams consisting of 3 to 5 students each.

With rule 1 in mind, the overriding question is how to select student teams? We suggest instructors balance teams so that each team member brings some special talent or expertise to the table [4]; clearly teams need more than analytical ability, although each team should include a competent academic student. Specifically, consider the following:

1. In class 1, consider giving the 'mechanics readiness test'. (This exam is computer graded and can be accessed on the network [5].)
2. In week 2 or as soon as enrollment settles, each student completes a preparedness evaluation by responding to a list of queries chosen by the instructor (see note 5 below).

For example, these might address a student's:

- ability level in statics and calculus (teams need analysts).
- ability level in design drawing (teams need conceptually visual people).
- ability level in freshman design (teams need experienced people).
- participation in organizations and sports (teams need facilitators).
- interest or excitement level for Mechanics of Materials (teams need 'gung ho' people, but not members with widely disparate attitudes or goals).
- achievement expectations in the course (very high achievers should not be matched with very low achievers).

3. In the first two weeks, give 15-minute quizzes (at least 3), announced in advance or not.
4. In week 3, students submit (a) special schedule constraints (athletics, commuting, activities, etc.) that may interfere with teamwork and (b) choices of preferred teammates and why. Note: students should be informed that the instructor is not obligated to honor special requests. Grouping friends together is not recommended.
5. In week 4, the instructor reviews the above information to form teams of 3 to 5 students. We suggest the instructor select all members of each team, but student preferences may be considered. In large classes, this can be time-consuming to complete, hence start with an important single criterion and merely check others for conflicts. A good starting criterion is excitement level for the course.

Notes relevant to Rule 1:

- Teams of three will optimally involve members in a project of the size considered here. A disadvantage is that some teams will be decimated if members drop the course. Of course, other teams of three can absorb members of decimated teams who must be redistributed to other teams (or formed into new teams). To minimize such disturbances, we strongly recommend teams of four students with teams of three a minority [6]. Teams of more than five should be avoided.
- No more than one athlete or commuter should be permitted per team because these students usually have difficulty scheduling team meetings. However if sufficient students have similar schedule constraints, they may be grouped together.
- Assessment reveals a surprising number of students who hold low excitation and/or achievement expectations for the course. We recommend not grouping unexcited with very excited students; secondarily, we avoid grouping very low achievers who also harbor low expectations with very high achievers.
- Clerically form teams by grouping self-evaluation ⟨paper⟩ forms. Staple together forms for each group and assign it a name, e.g., Team A, Team B, etc. Announce teams to the class, have them meet, exchange names and addresses in writing and sit together for the rest of the semester. Notes and team grades may be recorded upon the topmost 'team form'.
- We do not recommend giving the Myers-Briggs Type Indicator test because our criteria for team selection does not fit into the MBTI categories. (The Myers-Briggs Type Indicator and MBTI are registered trademarks of Consulting Psychologists Press, Inc. Information can be found at http://www.cpp-db.com/cpp4.htm.)

Team activities

The primary activity of each student team is to solve the design project and write a report. To this end, one sample report is provided in notes issued to students, another is available on the World-Wide-Web. A secondary activity is to conduct a peer review of another team's report. Doing this task tutors both the reviewers and the authors on how to write a design report.

We also suggest that students be encouraged to solve all design problems in the course as teams and also study together and learn from each other. We further suggest that class time be made available for teamwork. In-class tasks may involve the student teams with questions on lecture material; for example:

- give 5-minute team exercises on connecting kinematic displacements to strain states and to stress states and sketch the resulting stress distributions,
- have teams collaborate on approaches to solving an example problem or completing part of a problem introduced in the lecture,
- project a realistic picture of a loaded structure onto a screen and have teams draw models featuring supports and loads (like most illustrations of problems in texts) and then write mathematical equations for the boundary conditions and draw free body diagrams. (Modeling is not trivial and students must learn to do it.) Although such tasks should be light and easy, some tasks may be made more enjoyable by turning them into competitive contests.

Success with such active learning methods requires preparation and planning; extemporaneous activities will not work consistently.

The objectives here are to foster team dynamics and cohesiveness, collaborative learning and to encourage students to participate actively in class. Our hope is that students will increase individual knowledge by working together collaboratively and through such interaction will apply and enhance team skills learned in their freshman design class. Unfortunately for the most part project work was simply divided between members to efficiently save time rather than carried out in a collaborative manner and some reports which were clearly pieced together reflected this. However class participation did increase when discussing design projects, but this did not carry over to general matters. The problem is simple. A majority of students seldom come to class prepared.

Rule 2. Teams should be assigned one 9-week design project for the 16-week semester with deadlines for (1) a preliminary design report and (2) a final design report, both written.

Notes relevant to Rule 2:

- For students to interact within teams in class, the classroom must not be furnished with fixed-to-the-floor, in-line seating. At a minimum, moveable seats are necessary.
- Communications with teams and students should be open. Only personal matters should be private. If a question of value to all is raised, make certain everyone learns of it and the reply. E-mail works very well. The World-Wide-Web provides excellent support.
- Writing is not taught, but a report format (Appendix 1) is issued and the sample reports provide guidance. Writing is lightly graded.
- Disfunctional teams. Rarely does a team fail. But it happens. First it is important to avoid problems by spending some time discussing proper team dynamics and member roles [4, 7]. Second, treat symptoms of trouble immediately; members of the team appreciate thoughtful intervention. Keep communications open; e-mail is very effective to learn of trouble; monitoring teams is likewise revealing. If troubles persist, dissolve the team and do it as early in the project as possible, within four weeks. Rule of thumb: if three discussions with the team together or individual members don't resolve the problem, dissolve the team and distribute its members to other teams, preferably with their prior agreement.

Monitoring teams and their solution of the design project

Teams and their solution of the design project must be monitored regularly. Progress can be assured by setting milestones and checking their passage. The objective is to get teams working effectively soon after the project is assigned, keep them working until it is due and ensure that proper design procedures are learned and employed. Furthermore, students need a degree of structure to develop their team approach to the project and faculty need a means of assessing its progress and assigning grades. We suggest the following be scheduled on the syllabus and announced and explained in advance:

1. Week 4: Assign the design project. Explain the schedule and set milestones so that the preliminary report and final project due dates occur several classes prior to exam 3 (in the 14th week). The time of deadlines should be the start of (not during or end of) class.
2. Week 5: Concept plan. Have each team member sketch their concept of the design and summarize in several sentences team activities to date and their suggestions for the design. Attach these 'concepts' to a team concept plan decided upon by consensus which should include a concept sketch, a listing of live loads, a ranking of candidate materials and an outline of the team plan (meeting schedule, summary of tasks and the next task). This can be used in determining the design report grade and individual team member grades (see grading below).
3. Week 6: Modeling quiz. Given individually, this tests students' ability to convert a simple, realistic structural system into an idealized model and analyze it.
4. Week 6 or 7: Mid-project peer grade. Each team member grades herself or himself and other members of the team by secret ballot, completed out of class, and handed directly to the instructor at the beginning of the next meeting. The instructor may then counsel underperformers or even reprimand uncooperative

students and in extreme cases transfer them to other teams or to a new team composed entirely of such students. Importantly, everyone must know the peer grade counts toward the project grade. A peer grade form is shown and explained in Appendix 2. Note: privacy of peer grading is important.

5. Week 7: Modeling sample. Each team member submits a completed design of one structural component from their project. It should include a sketch showing the location of the component in the structure; a model of the component removed from the structure with boundary conditions, loading and known dimensions; analyses with free-body diagrams to determine an unknown dimension and a decision on nominal dimensions.
6. Week 8: Status report. Each team submits a report on status of the project including complete design of at least one component.
7. Week 10: Peer review. Collect draft reports and assign them for peer review. Teams turn in draft reports to the instructor who then turns each over to another team for a peer review based upon a report format issued by the instructor. Each reviewing team will return the draft reports to the instructor together with a typed team review of the draft report summarizing all team member comments and signed by each member of the team. The instructor then returns draft reports with reviews to the draft report originators. This review will be turned in with the final report (see next item). Peer reviews should be collected within one week. Note: Peer reviews by individual team members may also be collected to enforce serious participation by each in this task.
8. Week 13: Collect the final design report at the start of class. It will consist of the design report, the peer review of the draft report and an item-by-item response to the peer review. Note: The peer review of the draft report is graded with the response to it and returned to its originators together with their graded report.
9. Week 14: Post-project peer grade. Similar to mid-project peer grade discussed above (see Appendix 2). This should be done prior to returning the graded design project in order for the project grade to not influence student peer grading.

Further rationale underlying the above are:

- Item 2 seeks to measure creativity of individuals, their contribution to the team and the organization of the team; it also encourages team members to prepare for team meetings.
- Item 3 provides feedback to team members so they can adjust if necessary their level of activity and informs the instructor of team dynamics.
- Item 4 addresses the goal of using the design project to improve individual understanding of basic mechanics concepts as well as their progress in learning engineering design.
- Item 5 is an example of cooperative learning whereby each team critiques another's draft report and each learns from the process.

It is important to provide guided design throughout the project. Milestones 2 and 4 foster project-related discussions prior to their due dates and feedback afterwards. Further guidance is given through frequent treatment of elementary, generic design problems both in class and for homework (Recall that design problems are set in the syllabus). Repetition of the design process makes learning happen. One sequence to follow is: demonstration, theory, analysis, design; others are modest variations of this.

DESIGN PROJECT GRADING

Design project grading consists of evaluating the final design report and assigning an individual project grade to each team member. The individual project grade is a composite of all grades received on project performance: those listed above plus optional peer grades. We suggest:

- Using the concept plan report and modeling sample qualitatively to at most shift an individual border line grade plus or minus several points out of 100; such a shift may apply to the entire team. In essence, these milestones are 'sticks' to coerce the teams to act and learn. Their evaluation serves as diagnostics of team performance and feedback to guide students through the design project.
- Grading the modeling quiz quantitatively and combining it with other quiz or class performance grades. Hence this grade will not affect the project grade.

The peer grades are treated below.

Rule 3. The grade of the design project is to be weighted 12% of the course grade.

Grading the final design report

The final design report should follow the report outline (see Appendix 1). This is issued to the students to provide structure and to facilitate grading. Points or weighting should be allocated to each section and communicated to students prior to report submittal. We suggest the following distribution out of 100%:

1. The design summary—drawing and bill of materials (20%): The drawings or sketches should be near to scale, clear enough to permit fabrication and done using professional technical conventions. The bill of materials may be a simple list, but adequate to make purchases.
2. Methods (10%): This is an outline of team strategy and the approach used to solve the problem.
3. Assumptions and warnings (10%): These should

list rational assumptions which enabled the design. For example, one may assume a stress concentration for a round hole applies to a slot. It should not include generalities or givens or facts. For example, material property data found in a cited source are not assumptions. Warnings list portions of the design which are not analyzed because, for instance, they are beyond the current level of student knowledge. It is important to explain to students that engineers rarely have sufficient knowledge to analyze everything regardless of their level.

4. References (10%): References should be cited in the body as well as listed.
5. Analysis, modeling and free-body diagrams (30%): Models and free-body diagrams should be required even in simple circumstances.
6. Quality (10%): Grammar, spelling, format and overall neatness.
7. Peer review (10%): Five percent for responding to reviewer comments. Five percent for the peer review of another team's work. Hence the peer review is used bilaterally: the team receiving the review should be graded upon their response to it; the team writing the review receives a grade on the quality of the review.

Note: Conformity in grading between sections taught by different instructors is only loosely maintained by using these guidelines.

Assigning individual grades

Human nature being what it is, some students over-perform and others under-perform, perhaps even purposely (so-called 'free-riders'). Hence individual performance must be accounted for. After grading the final design report, grades of individual students are determined by a linear formula based upon the student peer grades (Appendix 2) and the project report grade. In turn, this grade may be slightly adjusted using the concept plan and modeling sample grades (see above). This process works as follows:

1. Weight the mid-project peer grade f, the post-project peer grade $1 - f$ where f is no greater than 0.2. Low weighting on the former grade makes it more of a warning, which is its intent.
2. Then: Peer grade $= f \times$ Mid-project Peer Grade $+ (1 - f)$ Post-project Peer Grade.
3. Make the grade adjustment per the following formula:

Individual Project Grade

$$= \frac{\text{Peer Grade}}{\text{High Peer Grade}} \times \text{Project Report Grade}$$

where High Peer Grade is the highest average peer grade received within a team. All members who earn it, receive the Project Report Grade. Others with lower peer grades receive lower grades. If everyone in the team receives the same average peer grade, then everyone receives the Project Report Grade. This commonly occurs.

Notes:

- Two measures are made in determining the peer grade: quality and effort bases (Appendix 2). Why? Because students interpret quality as intellectual competence which, in our experience, is less discriminating between near equal performers than level of effort. Of course the effort basis is a 'zero sum' which forces more thoughtful consideration of who gets what. Moreover students are very aware of effort expended on the project. Numerous cases turned up where students with equal scores per the quality basis received unequal points per the effort basis, hence it often provides a finer degree of distinction. Furthermore, students somewhat lacking in talent can compensate by working harder.
- If a student fails to provide peer grades, that missing contribution is simply ignored.
- No individual project grade is higher than the project report grade. The lesson here is that no one can be compensated above the value of the product. This goes hand-in-hand with other skills project work teaches, namely, how to interact in teams, how to lead as well as follow, and the realization that everyone's effort must be mobilized for the sake of the product. If the project is deficient, then so is the team and all members must pay the price.

FUTURE DIRECTIONS

The future of planned management of courses and their delivery is of increasing necessity. In this paper we focus upon planning prior to entering the classroom and only mention delivery of education in passing. With teaching no longer a casual endeavor, we foresee careful planning and near-choreographed delivery as necessary to teach diverse student populations economically using multifaceted classroom technologies and instructional methods. Future tasks for this management plan are to tackle the educational delivery system and further automate the grade data system.

CONCLUSION

We have presented a meticulous management and grading plan for teaching design in a topic-packed analysis course. A step-by-step plan is crucial to success for instructors and particularly students who require such structure to guide them through a rather formidable learning process. This plan reduces the burden of teaching and learning design in a traditional classroom setting and it is open to continuous improvement in a systematic manner. The plan also provides an efficient method for determining individual grades for students working in teams. By following this plan, we find that sophomore students can learn mechanical design in an introductory mechanics of materials course. Moreover we find the majority of students more motivated by learning how most engineers apply analysis.

In addition, we discovered that design could not be added to an analysis course as an overload. One unmentioned objective of this plan is to avoid that situation. We did this by making room in the course syllabus for 6 hours of design and by including design problems in the homework. Whether or not we have the optimum assignment load and mix of topics for learning both analysis and design will be revealed in a forthcoming papers on assessment of our work [8].

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APPENDIX 1

Design project report format

A design report should be of high quality (clear, neat, correct grammar and spelling and adequate margins) and follow the format below. It should be terse, well illustrated and not crowded.

1. Cov*er sheet.* It is recommended that the project assignment sheet(s) be used as cover sheets.
2. *Project drawings, parts list and bill of materials.* These summarize and communicate your design. Drawings must include (1) an isometric assembly with components 'called-out' and correlated with the parts list, (2) clarification of connections and joining of components and (3) detailed sketches as necessary. Use professional conventions. Include all dimensions. The bill of materials lists structural products and their specifications (materials, sizes and amounts) necessary to fabricate parts and off-the-shelf hardware. It may include weights and costs.
3. *Methods.* This section outlines your plan and /or approach and important methods used. It also addresses key design concerns such as design for assembly, cost, safety and environmental impact. Tie it to Item 7.
4. *Assumptions.* This section is a numbered list of assumptions necessary to enable the design. Justify each one. Cite them where used by number. (For guidelines, read the class notes.)
5. *Warnings.* This covers known deficiencies in the design which are beyond the scope of the project. It serves to alert other engineers who may continue the project. Do NOT use warnings to avoid doing design that you are capable of doing.
6. *References.* This section is a bibliography of references. Cite ALL references where used in the body of the report. References may include private communications and World-Wide-Web sites.
7. *Concept sketch.* This sketch reviews your preliminary concept(s), communicates initial ideas, initiates the design and supports your approach. Tie it to Item 3.
8. *Material properties table.* Display a table showing property and allowable values and reference sources. Below the table, provide sample calculations for allowable values. List reference sources in item 6.
9. *Loads section.* Present general live loads the structure must bear. If applicable, calculate dynamic load factors. Use sketches as necessary. Dead loads may be included during design. Cite all reference sources.
10. *Calculations.* Each includes a model, analysis and free-body diagram. The model displays the component removed from the structure or the structure itself with boundary conditions. Free-body

diagrams must be drawn even in simple circumstances. Calculations should follow a logical sequence and be used to determine dimensions or check critical stresses and deflections. Each calculation must be titled and briefly explained.

11. *Peer review and response to it.* The peer review of your preliminary design report should be attached to your final design report. Write a response to the peer review.

APPENDIX 2

Peer grade form

This form provides the instructor with Peer Grade data in order to determine your Individual Project Grade. The Peer Grade is the average of two grades: (1) Quality Basis and (2) Effort Basis.

The Quality Basis measures excellence of work done on the project and is given in percent like an exam grade with 100% the maximum. Each team member can receive the same grade, say 100. For your reference: >94 = A, 94 : 90 = A−, 89 : 85 = B+, 84 : 80 = B, 79 : 75 = B−, 74 : 70 = C+, 69 : 65 = C, 64 : 60 = D, <60 = F.

The Effort Basis measures amount of work contributed to the project and is given in points which are a portion of a total allotted to the team. The total points allotted equals the number of team members times 90 points, hence if each team member did an equal amount of work, each would receive 90 points. However if more points are given to one team member, one or more of the remaining members must lose that number of points. You can think of this as dividing up the profit earned from sale of the product. For each team member INCLUDING YOURSELF, enter Quality and Effort grades and compute across each row the average of the grades you entered.

Table 1. Peer grades for TEAM

Team member name (alphabetical by last name)	Quality (%) 100 % max	Effort (Pts) 100 Pts max	Average
Check: Σ Effort = No. of members i.e. members × 90			

Your Peer Grade is the average of the average grades submitted by you and your team mates for you. Your Individual Project Grade is computed as follows:

$$\text{Individual Project Grade} = \frac{\text{Peer Grade}}{\text{High Peer Grade}} \times \text{Project Report Grade}$$

where High Peer Grade is the highest average peer grade received within your team. This member (or members) receives the Project Report Grade; others with lower peer grades receive lower grades. If everyone in the team receives the same average peer grade, then everyone receives the Project Report Grade. This is not uncommon. The individual project grade is subject to revision by the instructor.

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