The Use of "Supergroups" in Introductory Design Courses as a Motivational and Teaching Tool.

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Abstract:  
The author reviews the structure of an introductory mechanical engineering design course. Guidelines are laid out for the framing of design projects. A new scheme of project organization is described which incorporates large numbers of students in “Supergroups”

1. Introduction
The author has taught a second year introductory engineering design course for 24 years. This is a core course for mechanical engineering students - enrollment is about 120.
In this time, the author has gained understandings and made gradual refinements that may be of interest to those teaching similar courses. This paper will clarify some of the issues pertaining to design project-based courses.

2. Course Structure
The course comprises lectures with a series of practical design projects.
Each year, we begin with detailed instruction in engineering drawing and tolerancing. 2D and Solid modeling CAD software assignments are introduced.
The remainder of the session is concerned with practical engineering concepts and an introduction to the tools used daily by practicing design engineers. This material is straightforward, there is no text and students who attend and understand the lectures perform well on the final exam - which is the sole test we run.
The meat of the course, and the aspect that this paper addresses, is the practical design projects.

3. Design projects:
A typical semester offers 3 design problems in series, each of 3-4 week's duration - they are intended to stimulate conceptualization and force a proof of their concepts. These projects are performed by self-selected groups of three students.
Why do we, and so many engineering schools, use this model? The reason is it imbues in engineering students that important intellectual tool - a skill for conceptual design. Conceptual design is a developable ability - the working engineer's conceptual skills improve as she gains more knowledge of science and technology. Students, whose knowledge base is thin, can make rapid strides with well-designed conceptual challenges. Above all, the pedagogical value of the conceptual design project is to show students what others did with a level playing field and exactly the same rules. When this lesson is taken to heart, the students approach the conceptualization stage of subsequent projects much more seriously - realizing that a project's success isn't just about resources, people and equipment - its critically important to get the concept right.
Lastly, this point must be emphasized: Teaching conceptual design is a closed-loop process: the value of concepts is proven only by reduction to practice. So, the teacher is faced with the challenge of setting challenges. One of the first considerations is whether to set a "Real world product" or "Contrived Competition" problem.

4. “Real world” projects
Examples of the former might be an off-road wheelchair or an automatic pill dispenser. More exotic themes in this vein may be a remote planet rover or de-mining robot. Students struggle with a problem that seems to have commercial - or at least real-world - possibilities. Consciously or not, the question arises "why does this not already exist?". Could it be that no enterprise has yet marshaled the exuberant creativity of our students? Alas, the reason is invariably that a viable solution is not possible, practical, or profitable. Here is the hazard to choosing the real world option: in the end, students become aware of the competition's artificiality. Such projects remain in a conceptual (aka "virtual") phase far too long - because it is the easiest and most
When the students begin to prototype, they are confronted by the shortages of facilities and knowledge possessed by their real-world "competition". In fact, the deeper they delve into the problem, the more obvious it becomes that they are glossing over very thorny issues. Accordingly, they start to behave in a "what does the teacher want for a good mark?" kind of way. At the final presentation, the students enter a contest in which the skills of presentation and persuasion are more important than those of engineering.

"Real world" isn't entirely bad. These projects can add interest to a resume aimed at the student's industry of choice. Furthermore, persuasion skills are undeniably useful in our world. There is also some value to the upfront user needs analysis that accompanies these projects - and certainly, understanding the depth of complexity of all manufactured artefacts is a lesson that cannot be learned too soon. The author has had some success with running a "tradeshow" project wherein students 'sell' their 'products' and rough out a model while attempting to estimate costs. These projects have offered stimulation to students of a sales bent; they are fun and exciting projects but are used sparingly since there teach so little about design engineering.

A parenthetical note on "real world" design: In the author's decades of teaching, no student project has ever led directly to a real product. Nor should it - the goals of education are very different from those of product development. We should remember the purpose of our courses - and that students are far too inexperienced, their resources too meager and their schedules too compressed, to embark on any real product development. On the bright side, every serious design student the author knows has gone on to a career of producing real products in profusion.

5. "Contrived Competition" projects
This is the second, and preferred option for undergraduates. These projects have some common aspects. One is the arbitrary artificial scenario: Examples are putting balls into baskets, building vehicles that race over an obstacle etc. The closest analogy here is sport. The goals do not satisfy any real-world need, but the clarity and simplicity of the goal, and the competitive arena can spur the students to efforts that transcend normal schoolwork. And this is our goal as teachers - to provide an unforgettable learning experience.

Contrived Competitions are of two principal types
1: "to a criterion" - e.g.: Highest mileage vehicle, or lightest weight bridge.
2: "head on head" - e.g. robots do battle for a bowling ball.

Generally, the author prefers "head on head" as these are more interesting to stage as a dramatic event. This is much the same as why soccer is more interesting to watch than shot-put. Though entertainment has little to do with engineering, if the competitive event can draw a crowd, the event is that much more important in the student's mind and more effort is deployed.

6. Guidelines for challenge setting
It is well known that framing rules that are novel and challenging as well as dreaming up problems that are fun to work on, is difficult work. For teachers willing to try, here are the criteria we have come to recognize as important:

The rubber must hit the road. Good projects culminate in a physical test of performance. A design project cannot have a report as its sole deliverable. Run a lot of short projects rather than one long one. This avoids staleness, allows the most time with the conceptual design phase and gives "new leaf" opportunities. Students are not haunted by their "bad judgments" - and can use the experience gained push on Schedule weekly milestones - students are procrastinators. In our course, we always set deadlines for sketches, a rough scale model, a trial model etc... Challenges must be novel - Students are efficient workers: if last year's solution is available, they'll copy it - and so they should. Our job is to keep them learning, not copying. Challenges must be simple, coherent and clear. The competition must be understandable by a lay spectator. Rule lists should be a short as possible. The ruling of a winner should be visible, unambiguous and not subject to measurement rulings. Above all - avoid rule changes mid-project. These will draw the ire of the keen students who start early. It also telegraphs an advantage to procrastination. A teacher who makes a inopportune rule change risks losing the enthusiasm of the class.

Design success should not depend on students' personal resources. A high mileage rubber band powered car derives a distinct advantage from well-machined parts and precision bearings. These advantages should be ruled out. Because our class is large and we have no machine shop facilities for them, we tend to limit materials to styrene foam, wood, duct tape etc. that can be shaped in the simplest workshop.

Problems must be posed that have no obvious solution - because we want a wide variety of concepts and we are teaching conceptual, rather than refinement design. This is the central dilemma of designing design competitions - the teacher cannot foresee what the students will invent - therefore there is a risk of a trivial solution or worse, a dangerous one. Such a realization may trigger a rule change. See the caution above.
Devise goals attainable by all. For example, a rope-climbing robot may be achievable by the few, but much of the class will be non-starters. Instead, knocking a block off a stand onto your side of the play area is something almost any device can do. The test is this: if our two weakest teams are placed against each other - will a winner still emerge?

Seek problems with an optimum rather than maximum or minimum: Beware rules that allow an unbounded parameter (e.g.: to maximize energy stored in a spring without due limit to its mass or size can lead to some dangerous results.)

8. Supergroups
To address the aforementioned issues – to allow more inclusion and involvement of the non-design students and yet provide a stimulating project for the innovators, the author has experimented for the last few years with a “supergroup” concept.

It is a cliché to state that teamwork is good. But how seldom we actually make it happen. Professional schools promote the work of the individual. In university, the only time groups are used is as a de-crowding device when facilities are limited. How rarely in an academic setting do we actually enforce the power of groups? Yet power there is – it is no accident industries are called “companies”. The collective power of a properly organized team is truly magnificent. It is the very definition of “synergy”.

The mechanics and teaching demands of running a supergroup project are complex. But the willing teacher will realize a remarkable result.

The first step is to establish a hierarchy of “design ability” within the class. We do this by using the results from an earlier project – a “real world” project is unsuitable for this. It is therefore critical to run an earlier “contrived competition”.

Since this qualifying project was performed in groups of three, the entire class’s groups are placed in an ordered list.

Now a design challenge is needed. What we seek here is a device or machine that is a system with separable, and independent components.

An example might be to build a 2 passenger human powered vehicle comprising chassis, drive wheels, steering wheel assembly, seating and safety system and roof. In this case, with 5 subsystems there is a need for 1 management group making 6 in total.

In our class, if we have 42 groups, we would therefore form 7 supergroups.

The hierarchy list is applied to equalize the strength in each supergroup. The top 7 groups become managers. After that groups are assigned according to their abilities and the difficulty of the task. In the example above, the weakest groups make the roof.

If there is a coterie of very non-design groups, these can be assigned to softer tasks, such as aesthetics, quality control, or safety testing.

There are a couple of hazards here. One is a blurring of the separations. Managers must be impressed with the need to keep the system modular. If they wish to vary from the dictated scheme they must make their request clearly in writing. But, in the example above, if they wanted to combine the driving a steering function, it would be disallowed. Another technique we have used to sharpen the modularity is to require rapid assembly.

7. Varied Goals and Abilities in the Student Body
The author feels that the talents to ‘think visually’, the restless urge to dream up inventive solutions and “build things that work’ are largely innate and cannot be taught but when it exists, it can be developed. Moreover, in a large undergraduate class of mechanical engineers, the portion possessing these qualities in useable form is surprisingly small. History shows us that the small numbers of these specialists is no hindrance to progress, however. The economic knock-on effects of the work of the inventive few is well known and, indeed, celebrated. The author recently asked a class of 120 "how many truly want to be mechanical engineers?" Shockingly, only about 50 put their hands up.

What, then, are the purposes of teaching a 'design' course to so varied a group of students? Some answers are:

- to convey that all technology is the result of human effort, that it is fallible, incomplete and must constantly change.
- to show that our industrial economy is in essence one big design competition in which they will participate.
- to awaken latent abilities in some and to develop them in others.
- for students whose goals are "operations" oriented to show how the designers think and work so that understanding will be mutually afforded.

While undeniably, companies depend on product innovators to create new business, there are enormous employment opportunities for engineers whose jobs are to sustain the business. Many of our students assume roles in Quality Assurance, production, purchasing, operations, facilities planning and so on. For them, the lessons of conceptual design are perhaps less resonant. Nevertheless, planned properly a teacher can offer every type of student a good design experience.
To wit, each subgroup makes, maintains and provides its own device. The job of managers, who have no actual building function, is to ensure that all the subsystems fit and function together. Students have reported using the Internet and solid modeling software to creative advantage in this regard.

In summary:

- each subgroup must be assigned an unambiguous task capable of being built and tested independently.
- the system should be one which is serially dependent.
- The types of challenges that are set are, as always, crucial: We have had success with large human-powered vehicles, large robots and a variety of assembly lines.

As a motivational tool, the supergroup concept has produced some memorable results. This can be owed in part to the extra social pressure to support a large segment of the class and not to allow it to fail. This makes real the concepts of reliability, redundancy and illustrates the need for testing. We have found that procrastination is unheard of in these projects: the force of the groups ensures jobs are done early – we find supergroups have time for operator training – they usually even procure a team uniform and logos.

Unlike smaller projects, there are seldom last minute panics and we’ve never seen outright failures in the competition – most astonishing when one considers the mathematical reliability hazard of serial systems.

Furthermore, many students, who are not 'mechanical' and have never built a working machine are astonished and stimulated at the complexity of what they can accomplish.

The coordinator groups get an early taste of management. All groups gain a tangible appreciation for scheduling, communication, engineering drawings and revision control in a large-scale system.

In summary, the "supergroup" method makes possible the teaching of ideas and tools that are not available in the conventional small-group scheme. And, it draws out of the students abilities they didn't know they had.