

Two innovations in JHU's two semester ME capstone course

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The two innovations – new for us anyway – are (1) requiring teams to apply for the available projects as for a job, and (2) requiring a substantial prototype at about the mid point of the work. (1) has made the teams happier and I think more functional, (2) means that all teams have an encounter with the realities of the work earlier, and then sober up considerably, with time to have another go. The relationship to learning of the life habits of designers is explored a little bit.

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Background: JHU ME Senior Design

What we do is not so different from what many of you already do.

- Industry sponsors
- Typical project cost to sponsor: about \$12k in recent years
- Teams of 3 or at most 4 students
- Two semesters
- Required 2 weekly reporting cycle so 6 reports in the Fall and 6 in the Spring
- Formal presentation to sponsors, Faculty and classmates in Fall, and another in Spring.
- Strong expectation that something will be designed and built (and tested, and documented) by the end.

Our students are possibly a little unusual because of both who they are and the emphasis in JHU curriculum. The students are from high-achieving, wealthy families and most are both talented and driven. The curriculum, however, is biased towards maths and modeling and, for my taste, does not have enough hands-on or real-world project experiences. The result is that students start their capstone year in an unprepared state.

I want to explain changes we made that seem to help, in case they will also help others.

The first is a way to assign the students to the projects that seems to work. For several years we have been doing it by a “job application” process, that is, individuals *or teams* are invited to apply for the available projects as for a job.

The second is a requirement, backed up with lots of support, to produce a substantial prototype at about the mid point of the work. We call it the Fall Prototype.

“Job application” selection process

When I first took over at JHU I was keen to observe rather than make changes. I was fortunate to have one year of overlap with my predecessor in teaching, Dr

Andy Conn, and his assistant Niel Leon. The method used at that time to assign students to projects was a form of systematic assignment as defined in ⁴. The instructors surveyed the class and formed a spreadsheet with various columns for each student. See Table 1.

Table 1: Survey used in Sept. 2011

Please rate yourself on a 5 points scale where 1 means “not much” and 5 means “lots”.

Area	Interest in doing	Capability
Fabrication		
Machining		
Welding		
Assembly		
Trouble Shooting		
Computer Programming		
Java		
Fortran		
MATLAB		
C		
Basic		
Other		
CAD (Program -)		
FEA (Program -)		
CFD (Program -)		
Electronics		
Testing		
Organization		
Leadership		
Public Speaking		
Technical writing		

The instructors then had a meeting to try to form the project teams. The aim was to find a way to gather the 50 enrolled students into teams such that each team

- Had at least one student who claimed to be strong in CAD;

- Had at least one who claimed strength in Leadership;
- And at least one who claimed strength in fabrication.

There was also an attempt to match students to projects based on the expected technical content. A few other constraints were also considered, for example to avoid putting a male student with three females, claiming this would lead to problems (it didn't). I also had a few private requests from students who begged *not* to be put with certain others.

We formed the teams and had what may be described as a fairly mediocre year. A couple of the teams were pretty dysfunctional. With the clarity of hindsight I thought I knew why. We tried to group students based only on technical competence but what really matters are traditional "soft" qualities such as

- Do the students trust each other?
- Do they know each other well enough so that communication channels are open and remain so?
- Do they have compatible timetables?
- Do they have compatible work ethics, that is, roughly comparable ideals about what "working hard" means?
- Do they have compatible ideas about whether it is OK to work mainly at the last minute or not?
- Do they have compatible cultural background e.g. are all of them from China? (This is a major can of worms I don't propose to open. I will just comment that, if a team want to work together, and they are all from the same non-U.S. country, I won't break them up)

I think my predecessor had the basic concept that students are not competent to select one another, and therefore wise faculty should do it for them. The justification was, "in industry you can't choose your friends".

The following year, 2012-13, and this year, 2013-14, the selection process has been done differently. The new approach is

- A book of project briefs is published about 10 days before the start of semester. The briefs have some technical background, aims, objectives, likely technology needed, for each of the sponsored projects. In 2013-14 our book had 17 projects on offer.
- Students have about a week to form teams and apply for the projects.
- Individuals may also apply.
- Each student was to appear on exactly three project applications.
- In each case the application was to show *why this* is the person or *this* is the team for the specific work applied for. Desire was not enough: the applicants

had to show how their background or interests related to the work.

In both 2012-13 and 2013-14, unexpectedly, the process of allocating students to projects went quite smoothly. It was possible to assign the teams so that, with only a few exceptions,

- Students were kept in teams they had chosen;
- The teams got projects they had chosen; and
- Most commonly, both of the above.

Why does this matter? Well, if you are about to start a substantial project, and it is a bit scary, you want to have people around you that you know and trust. You want colleagues who have worked with you in the past, and have helped you succeed. Even if that was only as homework partners or lab partners, you have some idea who is smart, who is to be trusted, and who should be avoided.

It also does not hurt at all if a team are assigned to a project they chose. Consider the alternative: a team of young folks who are told, sorry, you have to do *this* instead.

I noticed that in the first weeks of both 2012-13 and 2013-14 the teams seemed much more excited and engaged. It was the difference between taking a cruise with strangers, and taking one with friends. Or between taking a cruise to a destination you have chosen versus one you have not. Practically it meant that less time was spent in the early weeks of the project on what might be called social alignment. Teams were ready to go from the first day so more engineering was done. Success and excitement lead to more success and excitement. I think of it now as the early trajectory of the projects. The early slope was positive, and that is a good thing.

I should mention here that nothing is perfect. In both years we have allocated projects this way, there were a couple of students left over. These students had dug themselves a deep hole during the previous three years. They had earned themselves a reputation for some or all of:

- Dishonest or slippery communication;
- Having low expectations of themselves and others, for example low interest in the profession of engineering;
- Talking big and not following through, for example promising to complete some part of an assignment, then not doing it;
- Technical weakness or illiteracy, thinly covered by bluster;
- Oddness; character flaws.

Consequently when the time came to form teams for Senior Design, they found themselves applying as individuals. Really very tragic. I think it is fair to say that our practices and teaching do little to educate early year students about these issues. We pretty much leave it up to them to discover for themselves, for example,

how important personal integrity and hard work are. Maybe there is no other way to do it but the results can be harsh. By the time a reputation is earned, it is too late to change.

I discovered after writing the above that the question of team formation has been discussed for years^{4 5 6}. Arguably there is not yet a clear “best” solution. I will venture the mischievous comment that perhaps the method chosen by the instructor best indicates the *instructor’s* personality type. I would rather nurture established social groups, teams, within the larger social group of our design community, than try to play match-maker.

Midnight in a design project

If you teach using design projects you probably know about what I call Midnight. It happens at about the mid point of the work, which for us is the Fall Design Day presentation. It was very bad for our 9 teams in 2011, with many of them

- Depressed and in low spirits
- Frustrated because there seemed to be many ideas or ways forward, and the best was unclear
- Frustrated with team members
- Tending to check out or invest time in other areas rather than the design work

My innovation, probably known since the time of the Pharaohs, was to introduce a new requirement for all teams in 2012-13 and again this year: The Fall Prototype.

What is it? Importantly it is meant to be the *end point of the work*. Fully working, fully tested, fully documented. But in Fall, not in Spring. I tell them, get it done and you will be excused in Spring.

It works for JHU ME students, I think, mainly because of their low practical background. They tend to assume that everything is very easy. They believe, initially at least, in what I call “the reverse explosion”, that is, that every part of their design will jump together ten minutes before it is due, and it will all work well the first time. How could they know any different, not having had opportunity to observe it?

There is also a syndrome, again stemming from low practical background, of failing to appreciate the realities of manufacturing. For example that one’s initial drawings will tend to be unclear or may use technology in an awkward or expensive way. Also that everything done by an external machine shop takes *time*.

The Fall Prototype causes each team to have an encounter with all of that: to produce drawings, to have conversations with machinists, to experience delays in ordering, to have problems and setbacks. Suddenly the typical rather dreamy approach to project planning and the reverse explosion are exposed for what they are: childish, unrealistic and doomed.

Importantly, since this experience happens in the Fall, there are still some months to go before the final result is expected in Spring. There is time to reflect on team processes, on how to objectively evaluate performance, and on the design itself, with the chance to recover.

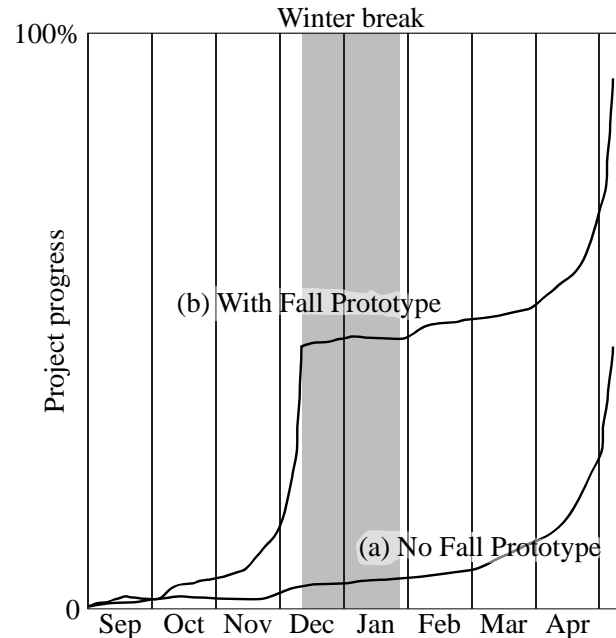


Fig. 1 Schematic: why the Fall Prototype works.

Another reason for the Fall Prototype is shown in Fig. 1. The Fall deadline, with expectation that the end result will be produced, gets the students to work as hard as they usually would near the end of Spring. During the winter and Spring, the teams start from the end point of the Fall and have *another* exponential ramp. The final state, I claim anyway, will tend to be higher than if there was no Fall prototype requirement.

Fall Prototype = Fail FAST

I notice that many of our students do not initially have much faith in the idea of *exploration* within a design problem. I mean the branching, positive-thinking approach that is so critical to the expert designer. What many students want is what they have nearly always had before: a nice linear run from the problem statement to the single correct solution. One driver here is student busyness. They are doing so much stuff in all their courses and lives that they have to find ways to contain design work to a reasonable boundary. If a faculty member says, “hey, you could also do it this way” the initial student instinct is then to shut down that line of reasoning fast because it will nearly always require work to check it out. As a rule they want a straight road with clear signs pointing down it, and find little pleasure in looking down the side streets.

The Fall Prototype means that something must be chosen fast at the start of the work, and developed to a

high level. The team will typically be passionate about this first attempt, believing it to be the best or right way forward. They have the experience of working through the design detail with this preferred approach, and then the even more important experience of revelation: this thing that they thought was great, was found to have problems.

Without much prompting, after seeing the problems, the teams are willing to go back to the drawing board. More sober now, and more willing to explore. Suddenly the practices of having more than one idea, and of developing more than one, and of exploring feasibility through modeling, seem more attractive. Anything to avoid another long saga with a dud at the end. Many learners have to discover these ancient truths themselves, and perhaps it is our role only to make sure that the discovery happens quickly.

Case study: team BRX 2012-13

Team BRX in 2012-13 were the JHU contestants in a national competition to design a lightweight, transportable bridge for the Airforce. The scenario was soldiers in a remote location and having to cross e.g. a crevasse in ice, or between two rooftops in a city. The perfect bridge would fold up into a light and small package yet extend to 20', quickly and quietly.

The team chose one another, wrote a compelling application and “won” the project. I can report that they remained a loyal, cooperative and responsive team.

Early in the semester the team saw a design in patent literature for a kind of collapsible bridge:

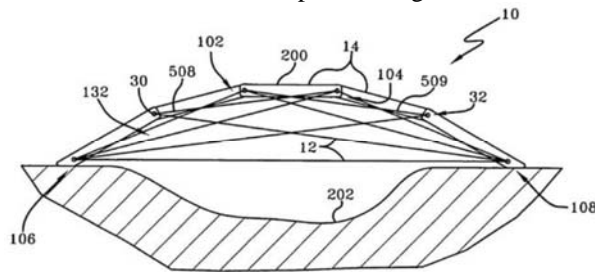


Fig. 2 Collapsible bridge concept, from ²

The team worked on this concept and did some force analysis on it (which later proved to be in error – but they tried). They resolved the design to the point where they had resolved the straight sections to a series of nesting, folded, heat-treated aluminium pieces. The tensile members were implemented as steel cables with swaged loops at each end.

During the usual creative phase of the work, the idea of an *inflatable structure* was proposed, but quickly dismissed by the team. They had their design which they *knew* was a winner – why waste time pursuing anything else?

The bridge pieces came in from heat-treatment and the team set about assembling their bridge, with just

days to go before the Fall Prototype deadline. Disaster! The design proved to be inherently unstable, and to depend critically on the elasticity of the wires. It could not be made to stand up by itself, let alone support service loads. To make matters worse, when it collapsed the sections moved against one another like a guillotine, presenting quite a nasty and unanticipated safety hazard.

Abashed, the team presented their result, or non-result, with reasonably good humor in December. More importantly, they went back to the drawing board. This time, all the supposedly crazy ideas from September were back on the table, and this time they would all be taken much more seriously. Inflatables were back. After trying several ways to use commercial airbeams, they implemented and later competed with the design shown in Fig. 3.



Fig. 3 Team BRX final design. From ³

The important thing here is not what the team built but what they learned from it. I think, I hope, they are now graduate engineers with a powerful new tool in their armory: a real, heartfelt belief in what their grey-haired instructors continually croak: *how else could you do it*. They got to that state because we compressed the timeline of the project brutally and required the Spring result in the Fall.

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