Junior Assistants in Senior Design Teams

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Some universities have sophisticated engineering design curricula which give students many educational opportunities within multidisciplinary and/or multi-year-level teams. Johns Hopkins University (JHU) Department of Mechanical Engineering (ME) however has not got there yet but we are keen to explore the possibilities. The innovation we report here is to embed some Juniors in established Senior Design teams in the second semester of a two-semester Senior Design project. Based on only two years of experience the signs are that this is a useful way to improve learning outcomes overall.

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Vertical integration

Families with children of various ages inherently produce a "vertically integrated" learning environment since all grow up together and share many experiences. It was at one time also the typical arrangement in a country schoolhouse, with all years at least sitting together, the youngest at the front of the class. The JHU Department of Biomedical Engineering (BME), ranked #1 in the USA, has had vertically integrated design classes for many years. Their design team course is offered at all year levels and projects tend to run for several years. The older students finish up and leave, and are replaced by freshmen and juniors.

However in the Department of Mechanical Engineering (ME) we have struggled to achieve that for historical and administrative reasons. The curriculum is full of technical engineering-science courses and does not have enough hands-on design-build experiences. This paper is to report on one small change that was made that seemed to work both administratively and educationally.

JHU ME Senior Design

JHU is a medium-sized high-ranked research-intensive university with about 90% tenure-track (teaching-research) faculty and 10% teaching-only faculty (your author is one of those). The university administration is quite devolved meaning that each level has a lot of autonomy and a one-line budget. Nine engineering departments compete to some extent for both students and the funding they bring. Only one of the departments (BME) has a quota or cap on undergraduate enrolment; the other eight grow or shrink over time, driven by student perceptions of both the quality of teaching and career opportunities.

Our ME senior design course (MESD) is special, at JHU, because it is the only one that now offers industry projects, mentors and funding. Right now only ME majors are accepted, but the projects include some electronics, instrumentation, robotics, control, computing, and embedded systems. We think it is correct for mechanical engineering students, indeed for students of any major, to be willing to tackle design work that is a little bit outside their comfort zone, an idea that has some support from literature[3].

The learning curve - design

Within ME, and prior to the senior year, students get some design engineering experiences:

- In freshman year, through a mouse-trap style competition;
- In sophomore year in an electronics & instrumentation course;
- In elective courses such as robotic assisted surgery;
- Through independent-study courses, a way for top students to enter research labs;
- Through involvement with extracurricular design projects such as SAE Baja;
- In junior year ME course "Engineering Design Process", the subject of this paper.

To this author's taste the above is not enough preparation for Senior Design. What is missing?

- Required machine shop inductions and substantial training e.g. the expectation that every student will make some set pieces on the lathe, the mill, by welding and so on.
- Courses that are based around a negotiated design-build-test project, with a faculty advisor, and based in a maker space or design studio.

We put students into lectures and tutorials because it is efficient and has become the tradition. But what gets

them excited, and what makes them into engineers, is the project work and the experience of being resident in a lab or studio.

Piaget[4] noticed that language is learnt best by immersion, and thought that we should try to teach, say, mathematics, by sending students to the land where *mathematics is spoken as the native language*. He also used the potent phrase *community of practice*. Students need to be in a community who *do* engineering. Schoen[5] developed that into the modern idea of the design studio. A young person sitting in a lecture is a student. But a young person building something in a studio is an *engineer*.

About 20% of our undergraduates enter a research lab before their Senior year, an important and celebrated Hopkins tradition. The other 80%, however, should ideally be resident in design studios and machine shops but we do not now achieve that.

Design Process teaching

The premise of much university teaching seems to be that one must prepare the student mind by a sequence of books and exams, with some set-piece laboratories to introduce science methods. Then, when sufficiently primed, the student is allowed to do some open-ended design-build-test work. Unfortunately this classic approach

- Bores many students and makes them question whether they made the right career choice.
- Creates an academic fairy-land in which students play with numbers without much idea what they mean and consequently make egregious mistakes.
- Introduces the real meat of engineering, which is arguably more on the side of communication, negotiation, planning, compromise, empathy, creativity, administration, manufacturing reasoning and teamwork, as a sort of afterthought.

Engineering Design Process was set up by this author and another JHU faculty member, Mo Deghani, in 2013. It was initially a junior level course intended to prepare students for Senior Design. In its first year it had a small design project: an international competition originating from Australia/New Zealand. In this initial form it was not a roaring success. Mo wanted to teach design-process material such as the product design life-cycle but it was done using examples rather than the context of a real design project.

Mo moved on and this author took over. The second year the Junior course ran, the students were asked to propose their own design projects, which were done within the Senior Design studio space. This was a little better. At least the Juniors now had reasons to visit and use the machine shops, and there was some useful transfer of skills from Seniors to Juniors.

In Spring 2015 the innovation was to assign Juniors to assist Senior Teams. Because our Senior Design course is two contiguous semesters, U.S. Fall and Spring, the available Juniors all joined Senior teams who were at about the mid-point of the work. Importantly our Seniors produce a substantial prototype in December, that is, the end of the first or Fall semester[1], and as a result

- The senior team had personal knowledge of the real world constraints of time and manufacturing relevant to their design project.
- Most of the design decisions had been made and are embodied in the Fall Prototype, for better or worse. In the strongest Senior teams all that remained for the Spring was to do a second iteration and test program.

In 2015 the 16 Senior teams were asked to consider whether they would like a Junior assistant and if so, to submit a proposal. The proposal was a one-page document explaining what the Senior team would ask the Junior to do. The Juniors were given some degree of choice about which Senior team they were assigned to. So it was an amicable rather than an imposed relationship.

Advantages seen included:

- The Seniors knew their way around the various machine shops and labs. They knew the training expectations and could also help design a manufacturing sequence;
- The Seniors knew this author and the other teachers well, and could give the Juniors credible advice about who we were and what our expectations were;
- The Seniors knew each other well and there was an established team dynamic. A miniature community.
- The design task assigned by the team to the Junior was typically a small part of the larger set of tasks. But since most of the big design decisions had already been made in the Fall, it was a small or well-defined problem. Some examples are given below. A problem of the right size is very important because when starting out in any discipline, the learner must have success pretty quickly.
- The Junior Assistant had the excitement of *being an engineer* on a real industry project earlier in their career.

Junior Assistants 2015

The Junior course was built around a weekly reporting cycle. One lecture was used to do exercises with the class of 9 (8 ME Juniors and 1 from BME). In the other lecture spot each week the students were asked to speak briefly about what they were doing with their Senior team, and this became a forum for discussion and assistance. Each student submitted a weekly report rich

in graphics. Juniors were also asked to take the available training in machine shops as part of assessment.

It is difficult to objectively measure the result of the experiment, because the story of each project, the personalities and background of both Juniors and Seniors, and the learning were all so individual. This author is convinced that the results were good, but it is unclear how to prove that to anyone who was not closely involved. Some case studies or stories about what happened in the 2015 teams are offered as material for reflection.

The students were assigned as follows:

James Webb Space Telescope (JWST) project, to build a moving 1:5 scale model of the telescope as a promotional piece: 4 Juniors; two assigned to the sun shields; two to the secondary mirror mechanism. Much of the frame of the telescope existed when the Juniors started, many detailed choices about how and where the various parts were joined had been made and there was clear demarcation of the sub-projects.

Baltimore Gas & Electric Co. (BGE) project to develop a full-flow oil-detecting valve: one junior assigned. The Senior team had decided already to detect oil using a commercial electronic device. They assigned their Junior to build prototypes of the valve itself, designs created, more or less, by the Senior team. Interestingly all 5 of the larger Senior+Junior team were very much into track & field which helped to align their schedules and perhaps also their work ethic.

AAI Textron Co., project to develop a custom attachment for a quadcopter. The Junior assigned to this work was asked to make a one-degree-of-freedom wrist joint with a motor and gearbox, to make it possible to change the angle of the attachment.

Walter Reed National Military Medical Center (WRV), lift-foot "shorty" prostheses project. One Junior was assigned to develop a very simple wooden prosthesis to improve the shape of an existing model.

The Space Telescope Science Institute (STAR) project to develop a calibrated light beacon for atmosphere calibration that could fly home after use. The Junior assigned to this strong team worked on various sub-projects including an LED mount, and checking the radio link strength.

The Lockheed-Martin Co (LMC) project to develop a way to move a shipping container in a constrained space. The Junior assigned to this work was chosen for it mainly because of strong background in machine shop practice which was very much needed by the Senior team.

Observations of Juniors becoming Seniors

The Juniors assigned to STAR and LMC clearly enjoyed the experience, struggled with some real design for their Senior team, learned a lot and became notably strong and confident Seniors.

JWST (telescope model): The 4 Juniors were more assiduous and energetic than their Senior team, causing an interesting problem with the balance of power. The Seniors wanted to lead the whole enterprise but soon found they were not in a strong position to do so, having not proven their ability in the Fall. This problem does not seem to have affected the development of the Juniors, three of whom are now Seniors, and who are strong and confident.

BGE (oil valve): The Seniors seemed to somewhat take advantage of their Junior, making him do some of the work that really they should have done themselves. But despite that the Junior said he enjoyed the experience and learned a lot. Interestingly this Junior has gone on to have a *less* excellent design experience in his own Senior team, who have squabbled a little bit. He confided in the author that he had found the previous team much easier to work with. In Fall 2015, as a Senior, he left some key work very late, a lesson that should have been well learned by then.

For two of the assigned students, the work was clearly defined but the Junior struggled and procrastinated (Walter Reed prosthesis project and Quadcopter attachment project). In each case it became clear that the Juniors deeply lacked the necessary prototyping skills, a common enough syndrome, and one was also busy with campus sport. Now that both have become Seniors, they have each developed, have taken a more mature or leader-like role and have done some good design-build work done in the Fall.

The "course quality" score from the anonymous end-of-course survey in the Spring was one of the highest I have ever had (4.20/5). In December I asked the EDP students, the former Juniors, to reflect on their experience. Three responded but space permits me to quote only some of the responses:

(1) "[being an assistant in the Spring] put in perspective the concept of trying to completely finish the design in the fall in order to maximize the amount of testing that could be done in the spring. Having worked on the JWST project in which we were still having to design seemingly to the last day, we made it a priority this semester to hit the ground running in order to give us as much flexibility in the spring as possible. In addition, I also appreciated the opportunity to get experience in the student machine shop, so that I would not have to worry about being trained this semester thus accelerating the design process in the Fall. Also, I appreciated the opportunity to improve my drawing skills, as I feel that this was an area I was particularly lacking in at the start of EDP."

(2) "Being a Junior Assistant gave my senior design team a huge head start in Senior Design. I knew how important it was to form my senior design team

before Spring 2015 semester ended as my junior design team had to join together at the last minute and as a result picked a project that they all were not in agreement on. My senior design team could immediately use both machine shops and knew about the supplies and manufacturing capabilities. Knowing what the slides for our client meetings were expected to look like and how important photographs were helped a lot. Knowing you and Soraya, and not being worried about asking both of you for help, was really helpful as we could get the help we needed fast… I ended up being a "real" member of my senior design team, and I think offering juniors that full experience of doing more than completing assigned tasks would be great if that is what the new juniors are up for."

(3) "It is because the program is structured much like senior design that the participants get so immersed in design, and if it were to be structured more like a traditional lecture, that would be lost."

Even in cases where – to the author's taste – the Seniors had taken advantage of their Junior assistant, or had not shown sufficient leadership capability to properly engage the Junior(s): even in those cases the result for the Juniors seems to have been positive.

The high course evaluation and the enthusiasm with which the Juniors (become Seniors) reviewed the experience encouraged our teaching team to repeat the experiment.

Second time around: Spring 2016

At the time of writing it is about half-way through our second Spring of assigning Juniors to Senior teams. This time there are about 20 Juniors embedded in a Senior class of about 60. By itself this is evidence of positive change because the Junior course is optional and students have much choice.

Although it is only the mid-point of the semester, it is possible to again call the experiment a success. Having taught the Junior class with both an artificial or toy project, and with Junior-chosen projects, it is clear to this author that the real-world environment of the Senior teams produces:

- Engagement with and enthusiasm for the work;
- Deeper encounters with manufacturing, drawing and technology;
- Alignment of expectations about reporting, assessment, communication, seeking help early, and prototyping.

As evidence of social integration of Juniors: within weeks of starting, most who attended the Senior progress meetings began to contribute slides to the progress report, and to speak to those slides, just as if they were Seniors. Also some of the Senior teams had to travel to visit client facilities at another state and chose to include their Junior assistant in travel plans without any hesitation.

JHU is a small enough university that the Senior and Junior cohorts do generally know one another and there is a strong informal network. In one instance in 2016 a Senior team chose a specific Junior before the general assignment, citing reasons of prior association and productive group work with that Junior.

The only slightly negative thing seen so far relates to timetable. Since JHU has a devolved or decentralized structure, students sometimes find they cannot attend every event in all courses. In Spring 2016 we had one student who was not able to attend the meetings between the Senior team and their client/sponsor. This led to a syndrome of poor communication and poor social integration for that student. This isolated example serves to show yet again how important it is to design the learning experience to support the *community of practice*, the working group doing the engineering. A student team must be able to meet each other often, and attend meetings with industry colleagues.

Conclusion

One semester plus one-half of a semester of experience has shown that assigning one or two Junior Assistants to Senior teams in the second semester of a two-semester design course:

- Reduced Junior anxiety about Senior Design;
- Improved Junior engagement with machine shops and with hands-on work and prototyping work, by showing how important these skills really are to success;
- Gave the Juniors one more time through the usual design-struggle-build process, preparing them for success in the subsequent Senior year.

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