Initial Lessons from Nexus Learning for Engineering Students Achieved Via Interdisciplinary Projects for Outside Clients

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Abstract
Philadelphia University's approach to education is called Nexus Learning. It emphasizes active, engaged learning; collaborative and interdisciplinary team work; and experiential real-world learning. Emulating professional practice, students participate in curriculum-integrated projects for external clients. These real-world projects are intentionally organized with a broad and changing mix of students from many different disciplines and academic programs including business, occupational therapy, industrial design, architecture, textile design, and fashion design. Engineering students in this university case study are relative latecomers to these collaborations. Therefore, the engineering program found itself having to adapt to the culture and expectations of other disciplines more than is usual for engineering undergraduate programs to fully participate and integrate into the culture of Nexus Learning and real world experiential learning.

Based upon observations from ongoing Nexus Learning interdisciplinary projects that include external clients, the obstacles engineering students and faculty encountered are stated, as are the initial approaches to overcome them. Challenges and approaches to overcome them include 1) proceeding with projects where technical expectations exceed course content by applying Just-In-Time Learning, 2) overcoming apparent differences between design approaches in engineering and other academic fields by incorporating an interdisciplinary lexicon into engineering courses, 3) using protocols for work presentation borrowed from other disciplines thus allowing for effective team work, and 4) coordinating interdisciplinary team work sessions and meetings with faculty and sponsors through deliberate course co-scheduling and classroom flipping.

2014-2015 is the first academic year in which all these techniques have been analyzed in engineering courses on projects for-credit. Based on initial observations, discussion is presented concerning what constitutes a good project; two example assessment instruments are shown (one instructor-based and the second peer-based); and guidelines are given for how students at different levels, bringing unique skills to each team, are managed and graded. Assessments from interdisciplinary teams' midterm presentations on an industry-sponsored project show that teams are generally weaker in "engineering skills" such as quantifying design requirements than they are in skills represented by other disciplines on the teams.

Introduction
Philadelphia University has developed a theory and practice of teaching and curriculum development based on signature pedagogies[1] and integrative learning[2,3] that since 2009 changed the overall student learning experience. The phrase Nexus Learning encompasses four overall approaches: 1) students are active and engaged; 2) they are involved in learning how to collaborate and work across disciplines; 3) their curriculum focuses on real world problems; professional training, and experiential learning; and 4) with all of these learning experiences

students are drawing upon and integrating a strong knowledge of the ways of thinking of the liberal arts and sciences. By themselves each approach is not unique, but the combination of real world learning with pedagogies that ensure active engagement and effective collaborative work do make for an integrative student learning experience that is different from other schools.

Rapid pace of change, encouraged by technology, has shifted engineering education to be less dependent on direct memorization of facts and more dependent on integrated skills including collaboration, creativity, interdisciplinary understanding, and the ability to communicate to team members with diverse backgrounds.[4] This conviction about learning is the core of Nexus Learning approaches. Applied to engineering education, this approach is transformative to STEM teaching because, at its pedagogical foundation, is the assumption that students are professionals the moment they enter their program and should be challenged accordingly. For undergraduate engineering students, the path for immediate involvement in professional practice is participation in interdisciplinary industry-sponsored design-and-build projects.

In a previous iteration of implementation, engineering students participated in industry-sponsored projects on an extra-curricular basis. Except in one carefully developed industry sponsored collaborative project, participation was not mandated nor was it tied to engineering courses for credit. Outcomes were mixed. A positive example arose from an annual weekend-long "sprint" project event that engaged almost 170 participants from multiple universities. Students, including engineers, identified and solved problems related to the aging urban population. Engineering majors who volunteered to participate helped their teams ideate digital medicine dispensers (Figure 1), urban agriculture systems, and folding flexible residential walls (Figure 2) among other innovations. By contrast, negative outcomes occurred on other interdisciplinary projects when engineering students who volunteered to participate became busy with regular engineering coursework and dropped out of full project participation at unpredictable times.

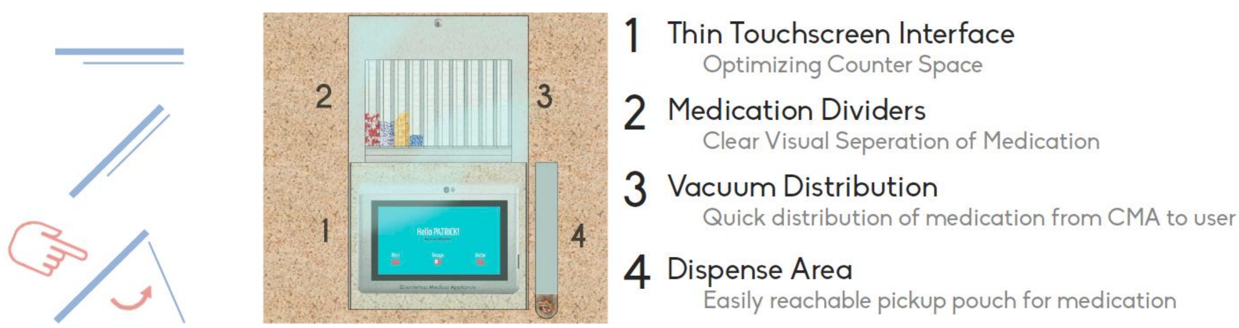

Figure 1: The Home Medication Device (HMD) was conceived by an interdisciplinary team including engineering students. For elderly people, the HMD reminds them to take medications at designated times, provides prescription information, and contains doctor and pharmacist contact details.

To encourage more broad and consistent student participation, engineering faculty are now incorporating into courses interdisciplinary design-and-build projects for outside clients by piggybacking on existing industry-sponsored programs offered by other disciplines at the university. Current collaboration team demographics include 1) M.S. Industrial Design, MBA, B.S.E. Engineering, and B.S.E. Mechanical Engineering students working with Johnson &

Johnson on new health product applicators; 2) B.ARCH Architecture and B.S.E. Engineering students working with Project HOME on urban farming structures for homelessness and recuperation housing; and 3) M.S. Industrial Design, MBA, B.S.E. Mechanical Engineering, B.S.E. Engineering, OTD Occupational Therapy, M.S. and B.S. Textile Design, M.S. Physician Assistant, and B.S. Environmental Sustainability students working with Verizon on wearable computers.

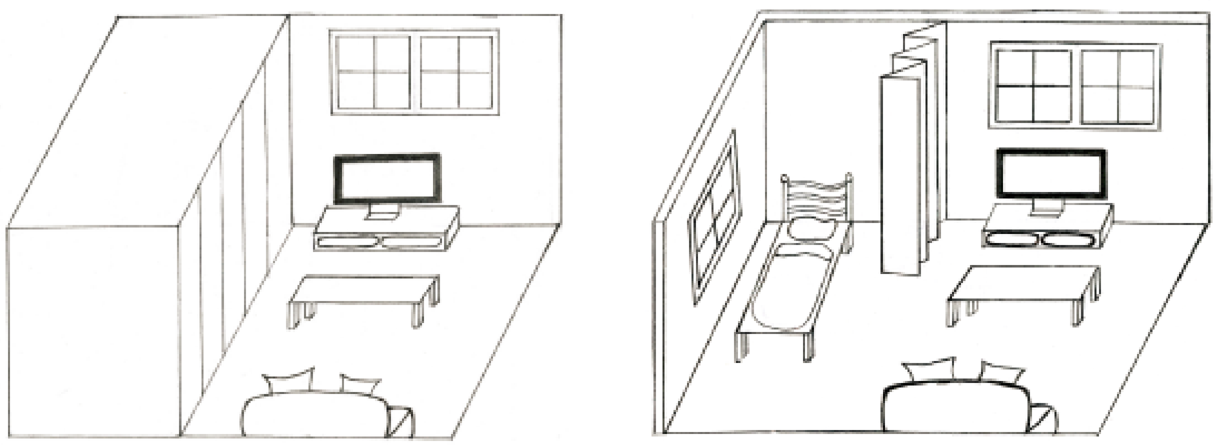

Figure 2: Residential Flex Walls, conceived by an interdisciplinary student team that included engineers, allows elderly individuals living with their families to alternately enjoy privacy or open their space to facilitate meaningful family interaction.

Literature Review

The introduction of outcome-oriented assessment included in ABET 2000, especially outcome (d) *an ability to function on multidisciplinary teams*, led most accredited engineering programs to provide multi-disciplinary experiences primarily through capstone senior design[5] while a few programs integrated these experiences into other courses.[6] Many such industry-sponsored project programs have long track records from which best practices can be gleaned.[7]

Central to many of these programs is provision of multi-disciplinary / interdisciplinary experiences for engineering students. Some programs have demonstrated success intermingling engineering with disparate disciplines to complete internally conceived projects.[8] However, curriculum-integrated engineering design-and-build projects conducted for outside clients highlighted in the literature remain mostly siloed within engineering. While these programs are certainly successful, their interdisciplinary dimension typically involves student or faculty collaborators from other engineering departments, computer science departments, or sometimes business programs. The tendency toward an “interdisciplinarity triad” in engineering projects is observed over at least a 20-year time scale (1990’s, [9] 2000’s,[10] 2010’s[11]). A current ASEE Prism article highlights some science, technology, engineering, arts, and mathematics (STEAM) collaboration examples, but it laments that the art community is driving collaborations and engineers should be doing more.[12]

In the research context, an accepted technical definition of ‘interdisciplinary’ activity is given in a National Academies’ report and emphasized by the National Science Foundation[13]:

“Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice.”[14] This definition can readily be extended to the formal engineering design-and-build process, which by its nature creates new artifacts or systems that solve problems and/or overcome challenges.[15]

The undergraduate engineering programs in this investigation were ABET-accredited for the first time in 2010 and are still relatively young. Thus, the practice of undergraduate participation in industry-sponsored interdisciplinary projects arose outside of engineering at Philadelphia University, and engineering is a relative latecomer participant in these projects. So, instead of providing the foundation and organizational underpinning typical in engineering design-and-build projects (like Capstone Senior Design), *engineering students at Philadelphia University are in the position of having to adapt to the culture and expectations of other disciplines to fully participate*. This necessary adaptation for participation creates a unique flavor of interdisciplinarity as well as a unique set of challenges for the engineering student participants. These challenges and how they are being overcome are at the focus on this manuscript.

Methods and Results

A key attribute of Nexus Learning based industry-sponsored projects is that external sponsors are paying customers with the expectation that students produce designs of utility that create value and have the potential for commercialization; in other words, the *stakes are real and they are high*. These real world problems, and corresponding real work opportunities, do not fit in the traditional silos of specific disciplines. In particular, solutions may come from unexpected and disparate disciplines, such as an engineering oriented problem being solved by a designer reframing it.[16]

Furthermore, there are multiple paths to establish industry sponsored and client-driven projects. One avenue is to leverage existing faculty associations with industry through alumni contacts, prior faculty research, or consulting relationships. To support fostering connections, the administration has created a vice-president for innovation, and part of that position is to identify external projects, secure sponsorship, and then to connect the right faculty members and courses into the collaboration. A key benefit to companies sponsoring projects is that student teams enter with “fresh eyes”. The most common feedback this approach receives from industry sponsors is that the company would likely never have come up with the students’ solution as the solutions are often outside the company’s traditional creative silos. Another sponsor benefit is that their staff fully participates in state-of-the-art innovation methodologies and learns from exposure to faculty expertise as well as from the innovation processes applied by students. This systematic incorporation of Nexus Learning has benefited dozens of companies over three years including Unilever, Newell Rubbermaid, Armstrong World Industries, and Federal Mogul. Evidence that successful Nexus Learning relationships provide value to companies and benefit to students includes 1) all corporate participants in the Nexus Innovation Program have become repeat clients providing multiple projects and 2) many project outcomes are being patented and/or pursued commercially by sponsoring companies. As these projects are propriety and confidential between the university and its client companies, they cannot be detailed here except in broad strokes.

Students benefit from these projects because they can apply what they learn in coursework to real challenges faced by companies. Philadelphia University students will work on multiple projects while earning their degree and will graduate with a portfolio of concrete results and experiences to show potential employers. The maturity students gain from directly interacting with working professionals over the four-year program also prepares them to have immediate impact on the organizations that hire them.

An important capability arising from engineering student participation in interdisciplinary projects is ability to assess ABET outcome (d) *an ability to function on multidisciplinary teams* from these projects. We define the requirements to accomplish this assessment by measuring against relevant course learning outcomes suggested by Felder and Brent.[17]

Within an interdisciplinary project team, each participating engineering student will be able to

1. Choose the best of several given strategies for a specified problem, and justify the choice;

2. Explain aspects of a project or product related to specified engineering and non-engineering disciplines; and

3. Function effectively on a team, with effectiveness being determined by instructor observation, peer ratings, and self-assessment.

To outline what constitutes a "good" project, two example assessment instruments are provided. To address the peer rating and self-assessment aspect of the third ABET (d) outcome, an on-line rubric-style assessment (Appendix A) is being used. It was developed from templates created by Reid and Cooney[18,19] and evaluated in a previous interdisciplinary project for an outside client involving industrial engineering and mechanical engineering content.[20] It has not yet been applied to the program currently being evaluated since it is meant to gauge the cumulative project team experience at the end of the term. In addition, an instructor-completed rubric (Appendix B) was created to address all three ABET (d) outcomes. It was applied to midterm oral presentations in which student teams elucidated their design and down-selection processes for project clients and course instructors. The results are given in Figure 3.

Discussion

An unexpected outcome from the midterm oral presentations (Figure 3) is that interdisciplinary teams in this study tended to be stronger in skill sets identified with the collaborating non-engineering disciplines and weaker in "engineering skills" such as quantifying design requirements, quantitatively evaluating design idea viability, performing quantitative idea down-selection, and keeping within project budget constraints. While this result requires further study, we hypothesize that observed weakness in "engineering skills" may arise from the dominance of other disciplines in industry-sponsored projects due to their longer legacy of participation. Thus, this outcome might be isolated to this particular study.

Teams with members of different skill sets and student levels are graded by instructors from each individual students' program in consultation with collaborating instructors from other disciplines. Instructors use rubrics or other grading techniques developed for their specific discipline (see Appendixes A and B for engineering examples). Applying separate grading schemes is important because different disciplines measure success in different ways. For example, assessment in industrial design is "ipsative;" it is based on improvement measured against an incoming baseline, which is different for each student. In other words, students are not graded on "ability", which is considered a conflation of "talent" with "mastery" or "accomplishment". Instead, industrial design instructors separate the talent with which one comes into a class possessing from the skills learned or built in the course. By contrast, student success in engineering assessment is linked to external content benchmarks. This is because students coming into a new engineering course typically do not innately possess the skills and knowledge required for mastery of that course. So "ability" can be measured directly by assessing skills using an absolute benchmark.

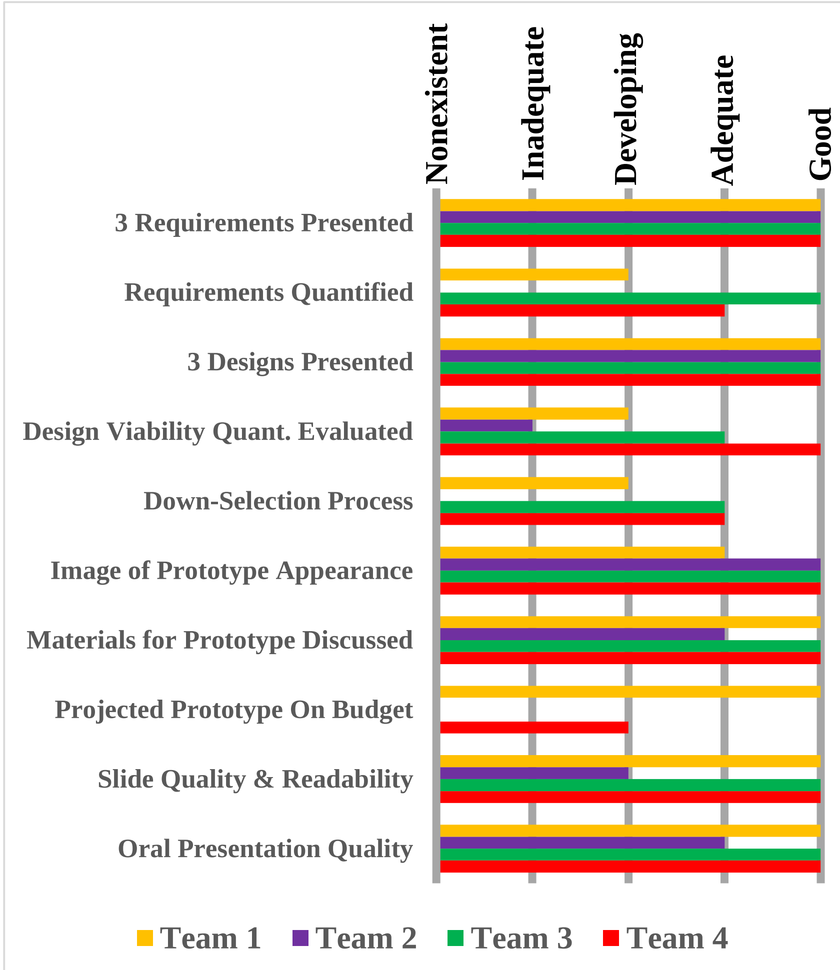

Figure 3: Rubric results addressing three relevant course learning outcomes suggested by Felder and Brent to measure achievement of ABET (d). Applied to an interdisciplinary industry-sponsored project, the evaluation shows that teams are weaker in "engineering skills" such as quantifying design requirements than they are in skills represented by other disciplines on the teams.

Because of separate assessment, students hailing from different disciplines working on the same teams do not necessarily need to meet the same requirements imposed on their teammates. However, for team assignments and presentations (Figure 4), students anecdotally report that they do feel compelled to contribute to teammates' success to facilitate reciprocation in helping meet their own requirements. This mutual respect for teammate success fosters strong collaboration and an understanding of the metrics defines "good" work across disciplines.

While this investigation has just embarked on piloting interdisciplinary industry-sponsored projects for credit in engineering courses, some challenges have already become apparent, and the experimental solutions in progress are further addressed. For others in the engineering education community, we feel these techniques can be implemented to create successful projects following the Nexus Learning pedagogical approach.

Figure 4: (Left) Students from engineering, industrial design, and business collaborate to achieve all goals imposed on the team by their individual specific disciplines. (Right) an interdisciplinary team, including engineering students, pitches ideas in a "charrette" format to an industry group from a sponsoring company.

Project Technical Requirements Exceed Course Content Coverage

Undergraduate engineering course content is traditionally relatively static. It can be difficult to align this static content with the complexity of industry-sponsored projects through course outcomes and content coverage needs. In analog to practicing engineers in successful businesses, the engineering students must often work in technical areas beyond what they have learned in the classroom to succeed on sponsored projects. This reinforces the need for lifelong learning practices where the students must constantly update and expand upon the statically taught material. This challenge has sometimes been viewed as an obstacle limiting undergraduate participation in projects with externally mandated deliverables; for example in research where publication is an expected outcome. However, as has already been shown for undergraduate research, [21] Just-in-Time Learning is a demonstrated successful pedagogy undergraduate engineering students can use to fill knowledge and skill gaps. This approach is particularly effective when students are motivated by meaningful project work,[22] as they are in sponsored projects when they are enabled and empowered by the ownership and value of their creative ideas.

For example, engineers in a fluid mechanics class working with Johnson & Johnson hit upon an idea to use shear-thinning fluid to spread a hair product across a customer's scalp without it running down that user's face or neck. Study of non-Newtonian fluid is beyond the scope of the undergraduate fluids course. However, with no prompting, the engineering students discovered in the literature a recipe for making shear-thinning gel using Carbomer along with a figure showing viscosities for a range of sheer rates.[23] They were then able to apply this information in a quantitative model to show how the gel would spread when applied to the scalp.

Incorporating an Interdisciplinary Lexicon into Engineering Courses

After starting from common origins, the design processes in engineering, architecture, and industrial design diverged.[24] Nonetheless, there remain striking structural similarities in many aspects of the design process across disciplines, which can be leveraged to promote effective communication and teamwork between engineers and students in other programs. What varies is the lexicon used to communicate and describe steps in the various design processes, whereas the underpinning activities and deliverables themselves are similar, as shown in Table 1.

Table 1: Industrial design and engineering design processes juxtaposed to show important and universal similarities.

Industrial Design: Design Process	**Engineering: Design Process**

1. Market Research
2. Design Criteria
   a. Customer Needs from Company
   b. User Observations
   c. "Mission"
   d. Design Brief
3. Brainstorm Possible Solutions "Initial Concepts"
4. Down-Selection to Best Solution
5. Prototyping
6. User Testing
7. Final Presentation
8. Present Final Design to Customer
9. Evaluate the Process for Improvement Opportunities
	1. Identify the Problem
	   a. Customer Criteria
	   b. Constraints
	2. Literature Search
	3. Brainstorm Possible Solutions
	4. Apply Constraints to Eliminate Impractical Ideas
	5. Quantify Viable Idea with each Criterion
	6. Quantitatively Down-Select to Best Solution
	7. Prototyping
	8. Test, Refine, and Troubleshoot
	9. Present Final Design to Customer
	10. Evaluate the Process for Improvement Opportunities

It is important for both faculty members and students to learn the design "language" of complementary disciplines and incorporate an interdisciplinary "multi-lingual" lexicon into the design process. Through implementing Nexus Learning, a common language is established and encouraged in the engineering courses by double-titling assignments associated with the project. For example, industrial designers perform "Market Research" while engineers perform a "Literature Search." Both processes gather background information and identify the state of the art in development and market opportunities of a particular product. To communicate this similarity to engineering students, their literature search assignment was named "Literature Search & Market Research," and they were encouraged to cite both technical literature and aesthetic literature.

Interdisciplinary teams present their down-selection processes to industry sponsors through design charrettes, following the protocol of architecture and industrial design. Prototyping to produce functional products is similar across all disciplines, and a working artifact is expected of teams. Testing, final presentation to the customer, and evaluation of the process are attributes shared and similarly named across disciplines.

Logistical Coordination

Complicating coordination among students of different disciplines are the practical logistics of 1) setting mutually-agreeable work session times, 2) formal team visits with faculty for assessment, and 3) reviews with sponsors to check progress and present final results. Several solutions are being tried to address the scheduling challenge. Courses that resonate with open-ended industry-sponsored projects are pre-identified across disciplines. These courses will now be scheduled during overlapping time blocks. If an industry-sponsored project is available, it is absorbed into these courses. Often, where scheduling misalignments cannot be addressed, the collaborative aspects of the projects become out-of-class homework, leaving class time for technical project support and critique. To free student time for interdisciplinary collaboration as well as faculty and sponsor meeting without loss of content delivery contact hours, engineering faculty flip some class sessions using on-line content. Typically, representatives from client companies are able to video-conference into classes during joint meeting times to provide feedback on student progress.

Another option being explored to coordinate student schedules across courses is to create a zero-credit-hour ‘project course’ that runs at a specific day and time each week. Students taking classes that contain industry-sponsored projects will co-enroll in the project course to keep that day/time free in their schedule. This approach to logistical coordination across disciplines will be tried in the spring semester of 2016.

Conclusions

The Nexus Learning pedagogy explored here crosses active, collaborative, and real-world learning while infusing it with the liberal arts. Participation in interdisciplinary industry-sponsored projects is a key method for undergraduate engineering students to experience curriculum-integrated Nexus Learning. However at Philadelphia University, undergraduate participation in industry-sponsored projects first arose outside of engineering. Thus, instead of providing the foundation and organizational underpinning for these projects, the engineering programs and students are in the unique position of adapting to the culture and expectations of other disciplines to fully participate. Moreover, the range of interdisciplinary collaborations being pursued exceeds the engineering-technology-business triad found in many curriculum-integrated interdisciplinary engineering design-and-build programs typically found at other universities.

A midterm assessment unexpectedly revealed that interdisciplinary teams in this study tended to be stronger in skill sets identified with non-engineering disciplines and weaker in “engineering skills”. To teach students how to function in a professional interdisciplinary context, flexibility and nimbleness, particularly among engineering instructors, is essential to success. In this manuscript we report strategies that address challenges already encountered Just-In-Time Learning is used to motivate and empower students to find needed knowledge when project technical requirements exceed course content coverage. Incorporating an interdisciplinary lexicon into engineering courses to show similarities in design processes across disciplines is enabled by dual-titling assignments. Protocols for work presentation, such as charrettes, are borrowed by engineering from complimentary disciplines to capitalize on the assessment structures already in place. Logistical coordination is accomplished by scheduling classes that share projects at the same day and time and flipping classes to allow students to meet in their teams, with faculty, and with project sponsors at days/times prescribed into their academic schedules.

The 2014-2015 academic year is the first in which these techniques have been considered or tried to facilitate curriculum integrated interdisciplinary projects for outside clients in engineering courses. Thus, this manuscript represents a work in progress and will be followed in the future by both anecdotal and quantitatively assessed evaluations of the effectiveness of these techniques to facilitate Nexus Learning for engineering students.

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Appendix A: On-Line Peer Evaluation and Self-Evaluation

Students will peer-evaluate all members on their design teams, including themselves, using the following metrics.

1. Contributions (Intellectual Quality and Management) of Group Member
Rate the quality of contributions to the project by each Group Member.

a. Member **routinely** contributed high-quality, useful ideas and information.
b. Member **sometimes** contributed high-quality, useful ideas and information, **or** routine contributions were **adequate**.
c. Member **never** contributed high-quality, useful ideas and information, **or** routine contributions were **poor**.

2. Division of Labor (Quantity/Accountability) Group Member
Rate the quantity and accountability of project workload shouldered by each Group Member.

a. Member made **significant** contributions of time in the project and was **accountable** to complete assigned tasks.
b. Member made **adequate** contributions of time in the project and was **somewhat accountable** to complete assigned tasks.
c. Member made **inadequate** contributions of time in the project and was **not accountable** to complete assigned tasks.

3. Communication Skills (Within the Team) of Group Member
Rate the communication skills of each Group Member in interactions with other team members.

a. Member maintained **consistent** communication throughout project and was **productive** in interactions with teammates.
b. Member maintained **adequate** communication throughout project and was **competent** in interactions with teammates.
c. Member maintained **poor** communication throughout project and was **unproductive** in interactions with teammates.

4. Professional Skills (Conduct) of Group Member
Rate the professional skills of each Group Member in interactions with other team members. (For example, appearing at meetings prepared and on time and treating other team members with courtesy and respect.)

a. Member maintained **consistent** professionalism throughout project and was **cordial** in interactions with teammates.
b. Member maintained **adequate** professionalism throughout project and was **courteous** in interactions with teammates.
c. Member maintained **poor** professionalism throughout project and was **belligerent** in interactions with teammates.

5. Discipline (Focus and Problem Solving) of Group Member
Rate the discipline of each Group Member in solving problems and using sound analysis when seeking solutions.

a. Member maintained **focus** on important tasks throughout project and used **sound** analytical approaches to solve problems.
b. Member maintained **attentiveness** to important tasks throughout project and used **adequate** analytical approaches to solve problems.
c. Member was **unfocused** on important tasks throughout project and used **questionable** analytical approaches to solve problems.

6. Synergy Contribution (Ability to Function in a Team) of Group Member

Rate the synergy contribution of each Group Member in functioning as a member of this team.

a. Member contributed to the team's **synergy** in collaboration.
b. Member contributed to the team's **adequate function** in collaboration.
c. Member contributed to the team's **dysfunction** in collaboration.

Appendix B: Instructor Evaluation of Midterm Design and Build Process

[Team 1]____

[Team 2]____

[Team 3]____

[Team 4]____

Score Definition: **0.00:** Nonexistent **0.25:** Inadequate **0.50:** Developing **0.75:** Adequate **1.0:** Good	Score			
	Team 1	Team 2	Team 3	Team 4
1. At least **three design requirements are presented** in the oral presentation.				
2. 3 or more **design requirements are translated into quantitative metrics** in the oral presentation.				
3. At least **three unique and feasible designs are presented** in the oral presentation.				
4. The **viability of each design concept is evaluated** in the oral presentation using the previously identified quantitative metrics as an evaluation gauge.				
5. A **down-selection process** points to designs that are viable and feasible to pursue for prototyping.				
6. A **system-level design showing how the prototype might appear** is given in the oral presentation				
7. A **discussion of materials and commercial-off-the-shelf (COTS) parts** to be used to fabricate the prototype is given				
8. **Budget** reflects materials, COTS parts, and custom parts described in the oral presentation				
Score Definition: **0.0:** Nonexistent **0.5:** Inadequate **1.0:** Developing **1.5:** Adequate **2.0:** Good				
9. **Quality and readability of the overhead slides**				
10. **Quality of oral presentation delivery** (each team member must speak at least once)				
TOTAL SCORE (sum of all scores):				