2018 ASEE Annual Conference & Exposition
Paper ID #23578

A Corporate Organizational Model for Scaling Class Size

Dr. Geoffrey Recktenwald, Michigan State University

Dr. Recktenwald is a lecturer in Mechanical Engineering at Michigan State University where he teaches courses in in mechanics and mathematical methods. He completed his degree in Theoretical and Applied Mechanics at Cornell University in stability and parametric excitation. His active areas of research are dynamic stability, online assessment, and instructional pedagogy.

Dr. Allison Godwin, Purdue University-Main Campus, West Lafayette (College of Engineering)

Allison Godwin, Ph.D. is an Assistant Professor of Engineering Education at Purdue University. Her research focuses what factors influence diverse students to choose engineering and stay in engineering through their careers and how different experiences within the practice and culture of engineering foster or hinder belongingness and identity development. Dr. Godwin graduated from Clemson University with a B.S. in Chemical Engineering and Ph.D. in Engineering and Science Education. Her research earned her a National Science Foundation CAREER Award focused on characterizing latent diversity, which includes diverse attitudes, mindsets, and approaches to learning, to understand engineering students' identity development. She is the recipient of a 2014 American Society for Engineering Education (ASEE) Educational Research and Methods Division Apprentice Faculty Grant. She has also been recognized for the synergy of research and teaching as an invited participant of the 2016 National Academy of Engineering Frontiers of Engineering Education Symposium and 2016 New Faculty Fellow for the Frontiers in Engineering Education Annual Conference. She also was an NSF Graduate Research Fellow for her work on female empowerment in engineering which won the National Association for Research in Science Teaching 2015 Outstanding Doctoral Research Award.

Prof. Anant Sahai, University of California, Berkeley

Anant Sahai got his BS degree in EECS from Berkeley in '94 and then got his MS and PhD degrees from MIT in '96 and '01. Before joining Berkeley as a faculty member in '02, he spent a year at the wireless startup Enuvis working on ultra-sensitive software-radio algorithms for GPS. His current research interests are in the foundations of information theory for control, low-latency wireless communication protocols to support the high performance Active IoT applications of the future, and wireless spectrum sharing (where his interests span machine learning, system architectures, game theory, law, and policy). In 2015-2016, he co-taught and scaled-up a radically new "introduction to EECS" course that is required for Berkeley EECS Freshmen and introduces them to circuits and systems concepts while teaching them linear algebra, all while doing interesting labs and application-oriented problems. In 2013 and 2014, he was also instrumental in helping scale up the sophomore discrete math and probability course to 500+ students. In 2017-2018, he is bringing this philosophy to the flagship machine learning course for EECS.

Prof. Matthew West, University of Illinois, Urbana-Champaign

Matthew West is an Associate Professor in the Department of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign. Prior to joining Illinois he was on the faculties of the Department of Aeronautics and Astronautics at Stanford University and the Department of Mathematics at the University of California, Davis. Prof. West holds a Ph.D. in Control and Dynamical Systems from the California Institute of Technology and a B.Sc. in Pure and Applied Mathematics from the University of Western Australia. His research is in the field of scientific computing and numerical analysis, where he works on computational algorithms for simulating complex stochastic systems such as atmospheric aerosols and feedback control. Prof. West is the recipient of the NSF CAREER award and is a University of Illinois Distinguished Teacher-Scholar and College of Engineering Education Innovation Fellow.

A Corporate Organizational Model for Scaling Class Size

Abstract

Many institutions are facing increasing enrollment in engineering and growing class sizes. This shift puts a strain on course management, resources, and quality student learning. Each institution of higher education has a different approach to dealing with large enrollments and the process for scaling a successful course will be different at each institution. Scaling approaches range from building MOOCs, to simply cloning courses, and to more complicated hierarchies of teaching assistants, instructors, and course coordinators. While the actualization of these approaches will differ by institution and are shaped by institutional needs and resources, there are a small set of basic course models that are utilized. Each of these models has benefits and challenges specific to its structure and will be common across institutions. In this paper we utilize a corporate development model to discuss the benefits and challenges faced by each of different scaling models. The goal is to build a framework and common language by which faculty from different institutions can dialog about their challenges and successes and build on the lessons learned from other institutions. This paper was developed by a workgroup at the 2016 National Academies of Engineering Frontiers of Engineering Education workshop. The goal of this paper is to open a dialog of how to continue to have rich and inclusive undergraduate engineering education at larger and larger classroom scale. We believe that this is an important and pragmatic conversation for many faculty in improving undergraduate teaching.

Introduction

Providing students with rich and inclusive education is at the heart of any institution. Even in highly intensive research institutions, the goal of research is arguably to push the boundaries of knowledge and educate others about what is found. As a part of this mission, a major part of student learning is the opportunity to learn. Learning is a process that is active[1-3], builds on prior knowledge[4], occurs within a social environment[5-7], and requires cognitive engagement in the process itself[8]. Research shows that assessing students in more in-depth ways improves student learning outcomes[9]; however, assigning a design project or holistic portfolio as an outcome rather than a scannable multiple choice test creates issues in providing timely and rich feedback in larger classes. We illustrate the relationship between rich feedback and class size in Figure 1.

Figure 1 illustrates the decline in the richness of feedback as the number of students increases. At the extremes, a small class (family business) can provide very rich feedback, but can only serve a small number of students. At the other extreme, a MOOC (massive open online course) might be available to thousands of students, but very little feedback is provided. The key goals of educational scaling are the creation of paradigms that can serve an increasing number of students as well as the refinement of those paradigms to increase the richness of the feedback provided to students. In our classes, students are not just looking for feedback on the “right” answer, but strive to be more conscientious consumers of feedback to improve their understanding of material[10]. It is essential for student development as well as fulfilling the mission of higher education to provide the feedback on real world problems that students so often seek. Engaging in "authentic" engineering learning is connected to the way students see themselves as engineers and reduces the likelihood of students leaving engineering[11-15].

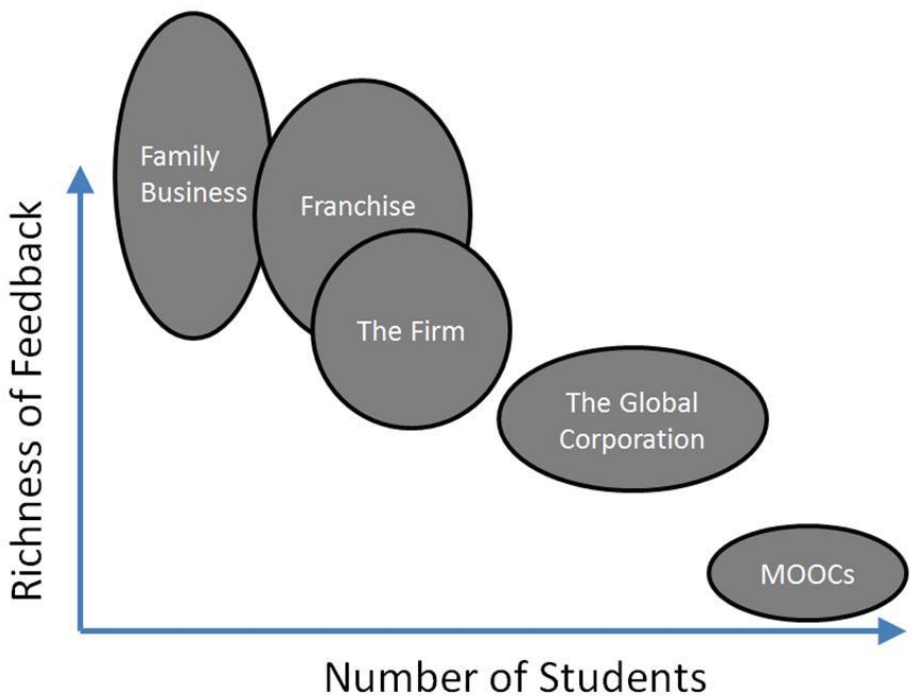

Figure 1. As the number of students increases, it becomes increasingly difficult to give the students rich feedback.

How does one go about transforming engineering education at scale? The ASEE conference is a great place to see the educational innovations of passionate and talented educators, but how do these innovations get adopted? It is hard for even the best educational innovations to transfer to a colleague's classroom[16] It is less likely for an innovation to be adopted by a different university. As a result, many engineering educators are re-inventing the wheel and excellent innovations are underutilized.

If educators had unlimited temporal resources this would not be an issue. But many transformative educational practices require teams of people to develop and test. Others are the result of a personal passion and decades of building, coding, writing, and/or tweaking. Educators do not have the luxury of dedicating years of effort to a project that affects only their classroom. Time and resources aside, many educators are not skilled or interested in developing educational innovations that are rich and inclusive. Transforming their classroom can only be done by adopting another educator's innovation.

The discussions in this paper arose as part of the discussions at the 2016 National Academy of Engineering Fundamentals of Engineering Education Symposium. The group involved in these discussions was looking at the problem of adopting and implementing innovations in engineering education. They quickly realized that adoption is highly dependent on context. Factors like college type, course size, teaching assistant support, student type, and faculty collaboration all affect the challenges one faces in adopting an innovation or disseminating an innovation. The primary purpose of this paper is to catalogue several of these factors and discuss the advantages and challenges of each one. The correlated narrative of business growth and development will be used to describe the differences between different course structures. It is hoped that the correlation will also be helpful in creating a conceptual framework with common language for dialoguing about adopting innovations that scale based on the structure of the course.

Scaling Issues

In a meta-analysis of class size and the relationship with instruction of 59 studies, Smith and Glass[17] concluded that "reducing class size has beneficial effects both on cognitive and affective outcomes and on the teaching process" (p. 432). In spite of the beneficial effects of reducing class size, engineering enrollment has steadily increased since 2008. The number of first-year students majoring in STEM has increased from 21.1 percent in 2007 to 28.2 percent in 2011, representing a 48 percent increase in three years[18]. Jacobs and Sax[18] hypothesized that this increase was related to the recent recession with millennials seeking more secure jobs. Additionally, this growth was not consistent across all STEM fields. Engineering saw the highest growth of 57.1 percent. These increases in enrollment place additional stress and burden on institutions and instructional staff and faculty. Large classes are not new in the university setting. Many countries, including France, Holland, Italy and the U.S., have classes ranging between 300 and 1000 students[19]. With these larger class sizes, come new challenges in providing rich and inclusive feedback to students on a large scale.

The recent shift in engineering education toward active learning also becomes more difficult at scale. The practical problems of students and professors dramatically increases and changes as a result of larger class sizes[19]. Students may not have the same number of peer or faculty interactions in a larger class which can reduce feelings of belonging, attendance, retention, and long-term academic success[20-22]. Additionally, instructors must cope with the large number of demands within a large classroom not limited to large numbers of students entering and exiting the lecture room, excessive noise-levels during in-class activities, reduced informal exchanges with students, and handling the large value of student evaluation and feedback[21,23].

Some advances in education technology have improved these issues, but the growing problem of engineering class size has not been solved. Automatic grading has come a long way in recent years and can provide more rich and adaptive feedback than before[24-26]. Many students appreciate the immediate feedback and opportunity to attempt problems multiple times. However, the impact of these approaches on students' motivation for learning is mixed and may more positively affect the majority group in engineering, white men, than other groups[27]. Other institutions have compensated for growing enrollment by hiring networks of graduate and undergraduate teaching assistants and graders. This approach brings additional organizational and cost burdens into large-scale teaching. Students in the classroom must be aligned with the mission of the course for both inclusiveness and quality of education, specific content taught, expectations of students both behaviorally and academically, plans for assessment, problem and classroom management, and the course instructional structure[28]. These considerations have significant hours and costs for hiring, training, and replacing teaching assistants on a regular basis.

The issues facing engineering education at scale have implications for student success. At the heart of the matter is meeting demands for higher fiscal accountability and efficiency for higher education with producing high quality engineers. This paper provides a conceptual framework for understanding the issues of educating at scale with also providing students with rich and inclusive experiences.

A "Business model" View of Education

Businesses usually start small, like a family business or startup. These small businesses achieve success around a particular product or service that the owners of the business can uniquely provide. In order to grow, they need to be able to train others in their methodology (business practices) effectively. If they are successful, they can expand or open a second store and grow into a firm or even a global corporation. Other businesses decentralize and become a collection of franchises[29]. In each stage the key to success is training others, adopting best practices, and building a culture of belief around the method. We use this metaphor as a conceptual framework to describe the different models of teaching in engineering courses at different scales. In the following section, we describe the advantages and challenges of operating within each model.

The family business

The family business is typically a small, but successful operation heavily influenced by generations of a single family. This business model is one of the oldest and most common models of economic organization. These enterprises, because they are small, typically have less reporting requirements and oversight than larger corporations. The business is run based on the ideas and values of a single group of people, and the organization can be agile to new ideas and adapt for change. These individuals keep institutional memory largely in their heads, with much passed on by oral tradition, and this suffices since the same individuals are active for a long period of time. However, the onus of running the business is also only on a few individuals, often with fewer resources and capital than larger publicly held enterprises.

Similarly, small classes are typically run by one individual or a small set of individuals, often with similar goals and values. These types of classes are widely prevalent in the U.S. education system, and dominate at small, liberal arts universities and colleges. The student to faculty ratio in the classes is often quite low with some schools having programs as low as 1:10 or 1:20 per class[30]. These ratios offer faculty the opportunity to take more risks in educational pedagogy and interventions within the classroom. These changes often have significant longevity as only one or two faculty consistently teach the same course from year to year. These smaller colleges and universities have more agile systems that can incorporate wide scale changes more easily for a school with a total enrollment of 800 students rather than a large, public university that serves over 2,000 in first-year engineering alone. Additionally, smaller class sizes that are autonomously run by a few faculty have an opportunity to create personal experiences that connect to students' interests. Assessment and feedback can also be more targeted and specific for each individual.

A successful example of this type of institutional model is Harvey Mudd College, a small, private science, engineering, and mathematics college. This institution took on underrepresentation of women in STEM by changing the names of its courses, reimagining the curricula, and finding ways to teach the required first-year computer science course in ways that were more authentic, team-based, and focused on communication. Now, the college boasts 49 percent of bachelor's degrees awarded to women and 38 percent of the faculty are women[31]. These numbers are well above national averages of approximately 20% female enrollment in engineering and computer science[32]. Additionally, Harvey Mudd outpaces the number of female faculty in STEM with national averages at 22 percent in information sciences, 19 percent in math, 18 percent in the physical sciences, and 12 percent in engineering[33]. This institution created a higher education environment in which women felt more included through changing the name and focus of its courses and reimagining the ways in which courses were taught. With overall numbers of 800 undergraduates and a student faculty ratio of 1:8, this institution was able to function like a family business in changing its strategy for operating in a competitive higher education market[34].

Disadvantages of this model include a heavy burden on individual faculty for change, potential loss of human resources and knowledge, and lack of resources. The biggest hurdle for curricular change is time and incentives[16]. Often smaller schools emphasize teaching as a part of their mission and focus, but teaching loads at these institutions are much heavier. At the same time, even undergraduate course curricula need constant revision to remain up to date as fields evolve. For a single faculty member to change a course, significant time and resources must be dedicated. Additionally, once this change is made, if the particular faculty member with the knowledge and skills to implement the course leave, the curricular reforms can be lost as well. Finally, faculty at smaller institutions often have less access to resources like teaching assistants (TAs) and dedicated IT staff or Scholarship of Teaching Centers to support change. Some may argue that reducing class size has significant benefits if the goal is to provide individual instruction. However, in the current higher education climate that is called to fiscal accountability as education costs rise, a cost-benefit analysis may conclude that the costs for reducing class sizes are too high for slight benefits[35].

The franchise

The franchise business model is to grow by duplication. The business framework and brand is provided by the franchisor, but each franchise operates with a relatively high degree of autonomy. The owner of the individual store, the franchisee, is personally responsible for daily operation and the success of his/her business. The franchise model can be operated at any scale, but the growth scales based on the number of franchisees. While the centralized parts of the franchise, like the supply chain, will benefit from economies of scale, the operational costs for each franchise do not benefit from the larger scale.

The ability to adopt change, or agility, of the franchise model is highly variable. Because the model depends on the value of the brand, many franchisors restrict franchisee directed innovation, but will likely have a method for top down innovation. This is particularly true for franchises whose brand is built on a particular customer experience or menu. Other franchisors have a very loose structure. They provide a brand name and access to a supply chain. In this case, the franchisee is free to innovate, but there is no organized model for ensuring that successful innovations are shared with other franchisees.

The franchise model is common within colleges and universities that desire smaller class sizes, but are faced with large enrollments. When student enrollment for a class exceeds a desirable size a new section is opened. The result is several courses offered by different instructors with identical course objectives. Each course instructor acts like a franchisee and the university is the franchisor offering it's "brand" and list of course objectives, but the structure is loose. Each instructor, the franchisee, has a relatively high degree of autonomy in how they achieve the course objectives. Innovations made in the franchise model are made in a single classroom and there is often no organizational model for ensuring that successful innovations are shared with other franchisees.

To an extent, textbooks represent another way that courses can be franchised across institutions. A textbook allows faculty at a different institution to adopt the intellectual innovations developed elsewhere and to follow the model, while still retaining a great deal of autonomy. Ancillary materials like solutions manuals, sample lectures, demonstrations, and the like can be considered as being the instructor-facing side of a textbook aimed at students. All of these correspond to the shared supply chain present in business franchises.

The franchise model has many benefits. For the college, it provides a proven model of scalable growth. For the student, it provides the advantages of small class size. Smaller class sizes are more likely to emphasize communication skills and open ended assignments[17]. For the instructor, the franchise model allows for the same agile innovation seen in the family business model. The franchise model has a unique advantage over the family business model; the ability to do controlled studies. Because several 'identical' courses are being taught concurrently by different faculty, students in a class with a new innovation, the test group, can be compared to students in another class, the control group.

A significant challenge of the franchise model is the scaling of innovation. The franchise model does not allow for structural innovations (e.g., adding recitations) since each franchise is autonomous. The autonomy and lack of institutional support for change can also make it difficult to share innovations across franchises. Without assistance, franchise level innovations are difficult to move beyond the beta phase, i.e., are not developed to the point that a colleague can use it without overcoming significant challenges[36]. Colleges have noted these challenges and developed faculty learning communities to help innovative ideas make it out of a franchise. Making or revising a new textbook is a major undertaking and it is unclear whether the existing financial or institutional incentives to do so are sufficient to encourage this.

Besides the challenge of scaling by duplication, franchises face a challenge of scaling by class size. Innovations that work with small class sizes do not scale to larger class sizes naturally. As class size grows, an individual student's interaction and the inclusivity of the classroom decreases[17]. Additionally, the implementation cost of the innovation may exceed the resources of the faculty. By way of example, innovations that increase the complexity of or time spent on grading often do not survive enrollment increases without additional support.

The firm: decentralized management

The firm is typically a medium size operation governed by a few principals, often referred to as partners[37]. These principals share in the management, business development, and revenue the firm generates. Some firms have equal principals and some have a hierarchy. The firm also employs non-partners who assist in the work under the direction of the principals. This type of business structure is often seen in law and consulting. Academic departments operate on a similar size and model. For the discussions in this paper, the size of the firm is bounded from above by a constraint that all partners must know each other. The firm is bounded from below by a constraint that projects are typically too numerous for a single partner to tackle all of them by himself or herself. The firm is run on the ideas and values of the partners. The agility of the firm depends on the size of projects; larger projects have more bureaucratic inertia, and the trust and communication between partners. Non-partners must be re-trained when new methods are adopted. The firm is large enough to strategize and provide bridge resources for longer-term changes.

Similarly, medium class sizes are typically run by a group of faculty and supported by a collection of graders or teaching assistants acting in parallel[38]. These courses enroll hundreds of students and use multiple lectures or recitations. Students are divided among the parallel recitations or lectures and among the graders. Due to their size, public universities typically have many classes that operate like a firm, but even smaller colleges may have a few core courses, like the calculus sequence, that operate like a firm[39]. The key identifier of a firm like course is the need to train the staff that aid in the operation of the course(s).

Any large pedagogical change made in a course of this size requires careful advanced planning. A key step in the implementation is training[40]. Instructions to graders must be clear, instructions to TAs may require practice or guided real-time instruction. Depending on the change, the TAs may need additional technical training, like running MATLAB or moderating a discussion board.

A key aspect of any team is cohesion. The teaching team must "buy in" to the changes. At a minimum this reduces the risk that TAs will revert back to “easier” or more familiar methods. At worst, the teaching assistants can revolt. Buy-in is also important because changes can require more time and may need real-time adjustments to deal with unforeseen challenges[41]. Finally, the students must buy-in to the changes[28]. This challenge means that the whole teaching staff must be able to confidently articulate reasons for making the change.

Some course changes require the instructor to obtain the agreement of their fellow faculty and/or chair. A structure change in a firm-like course, like the addition of a lab or inclusion of recitations will require the approval of department faculty and must pass through university bureaucracy. As such, structural changes can take several years to implement and may require proof of concept trials.

Giving quality feedback in a firm size course can be challenging even though the students themselves are divided into smaller groups. However, these smaller groups are handled not by faculty, but by graders or TAs who may not be subject matter experts at the level of the faculty. Furthermore, they do not have the same level of experience. The quality of TA feedback and grading is a serious pitfall for new changes. Care should be taken to monitor the TA feedback through the change process. Additionally, how TAs communicate through written feedback is an important area for training[42].

The firm size class has several advantages due to its size. First, teaching is done by a team of people so the burden of producing the resources needed to implement a change does not fall on a single individual[43]. The team also provides feedback on ideas and brainstorming opportunities that the family business does not have[44]. Second, large classes are revenue generators for the university. As such, colleges and departments are often more willing to allocate resources if the changes can be justified[45]. Finally, well implemented changes have been adopted by members of the teaching team, and do not depend on the involvement of a single individual. This means that academic success is not lost when the course instructor changes[16].

The challenges faced by a firm-size class are team size, overcoming inertia, building buy-in, and faculty exhaustion. Large classes are not as agile as the family business or franchise. Adaptations to unforeseen circumstances must be transmitted throughout the teaching team. Also because of the size of the class, small oversights can quickly deplete resources of time and/or money. All of these require careful planning and foresight. Large classes also have a reasonably high inertia. Changes require new training of both the teaching team and students. Finally, we have the challenge of buy-in. In a single instructor class, the instructor only needs to convince himself or herself. In the firm-style class, the whole teaching team must be persuaded to accept the changes[46]. For more significant changes the department must be persuaded as well. Dealing with all of these issues falls upon the faculty member(s) in charge of the course, and this induces an increased workload associated with teaching large courses in the firm style. In practice, when crises occur, the faculty member(s) in charge must triage problems and longer-term issues like adequate training or recruitment of TAs can easily be neglected in favor of solving the immediate problem.

The corporation: centralized management and specialized roles

A corporation is a group of people who legally act as a single entity (typically a *legal person* in most jurisdictions). Publicly-traded large business corporations are owned by their shareholders, but are typically run by a centralized organizational structure consisting of a single lead (the CEO or Chief Executive Officer) who controls a hierarchical operation with a great deal of specialization of roles and clear reporting lines and responsibilities. For example, there will typically be subsets of the organization responsible for different business tasks, headed by individuals with titles such as CFO (Chief Financial Officer) or CTO (Chief Technology Officer).

The neo-classical "theory of the firm" explains that corporations exist and are successful because they have lower transaction costs for coordinating the actions of large groups of people[47]. In principle a large group could coordinate their actions through one-on-one negotiations and interactions, but the overhead of doing this is typically prohibitive. A corporation with clear command structures sidesteps many of these negotiations by directly instructing people on what they should do and how they should do it.

When we think of running a course or set of courses on a corporate model, there will be a person (the CEO equivalent) who is empowered to make binding decisions about how the course will run, and who will be responsible for the various aspects of teaching it. This model is typically utilized in large enrollment courses that have a designated lead (like a course czar or superintendent) that sets the syllabus, text, and exams. The other participating faculty lack autonomy (relative to other course structures). They follow the czar's curriculum and teach their sections in lockstep with the other instructors. Depending on the specificity of the curriculum developed by the czar the other instructors may have varying degrees of autonomy. These courses can have many TAs who are typically managed by one of the instructors and operate recitations, labs, and/or help sessions.

The mathematics courses taught at West Point under Sylvanus Thayer[48] provide one example of a "corporation" course. For his classes, Thayer developed the Thayer method for teaching and utilized a team of instructors who taught individual sections using his method and reporting the progress of each student back to Thayer weekly.

The advantages of the corporation model are that it can ensure consistently at very large scale, and can be very efficient because people can be assigned to specialized roles that others can rely upon[49]. For example, the course CEO may direct one person to oversee the recruiting, training, and supervision of course TAs, while another person is tasked with content creation (writing exams, producing homework activities), and several others might be directed to deliver lectures. By reducing the need to constantly negotiate between these different faculty and TAs, the course can be consistency and efficiently run without overburdening any of the faculty involved. An immediate crisis can be handled without forcing long-term tasks to be neglected.

A key benefit of the corporate model is resources. Since a team of people is working on the course, the burden of developing an innovative approach can be divided among the team. By building innovations collaboratively, the team develops a sense of ownership and buy-in becomes stronger. The collaboration also brings a diversity of ideas and experiences to tackle obstacles. Having increased specialization of roles also allows for participation by staff members who would not be qualified to do more generalist roles. For example, undergraduate students who have just taken the course can help assist in labs even though they would not be qualified to do everything that a TA needs to do. Undergraduate or graduate students from different disciplines can help handle administrative tasks that do not require any subject matter knowledge.

The disadvantages of the corporate model for teaching can also be seen in business corporations. Large corporations are typically not as nimble as small startups or independent operators, and can be slow to react and adapt to change[50]. In an educational setting, a corporate course model can become locked-in over a period of many years and be very resistant to change. Corporate models of teaching can also be demotivating and disempowering for faculty, especially if the course CEO does not act to give faculty influence and a sense of ownership of their own educational roles. However, research has shown that course organization and instructor practices are more important for student outcomes than class size alone[51]. Students can be just as successful in these types of courses if they have the ability to engage in student-centered practices and still have personal interaction with the instructor.

A key difference between business corporations and the corporation course teaching model is in the appointment of the CEO or leader course coordinator and the metrics for success. In businesses, the CEO is responsible to the board of directors and, ultimately, the shareholders, who have no hesitation in removing a CEO who is not achieving financial success for the corporation. In a corporate course, the course CEO is typically appointed by a department head or dean, and it is much less clear how the success of the course should be evaluated with many different possible metrics (student evaluations, student course outcomes, student success in subsequent courses, faculty opinions, etc). The lack of an external ownership structure with clear success metrics can make it difficult to replace course CEOs, or to even know whether they and the course are performing well. Furthermore, unlike the situation of industrial boards of directors which often include CEOs from other firms (who therefore have some intuitive sense as to the challenges that face CEOs in general), in the educational context the course CEO might report to someone who does not have any intuitive sense of what is involved with running a course at this scale, and only has direct experience with family-business style courses. Establishing effective advisory boards for corporate-style courses may be something very important in supporting this mode of course.

The MOOC

We have specifically avoided assigning a corporate model to Massive Open Online course, or MOOC, in this paper. This is in part because the educational gains expected from MOOCs have not materialized due in part to the lack of rich feedback for the participants or lack of authentic participation of individuals[52]. While researchers and instructors are working on this problem, it is not clear what solution will achieve success. If a successful model of crowdsourcing feedback is achieved then the correlated business model is a company that relies heavily on contractors. If machine learning can provide rich feedback than the business model is the fully automated factory.

Conclusion

Transforming engineering education requires the adoption of innovative ideas. The adoption of innovative ideas is predicated on thoughtful solutions to the question of how the ideas scale. While there are many challenges and solutions to scaling and innovation this paper specifically addresses the challenge of class structure. The business growth analogy of the family business, franchise, firm, and corporation as models for classroom structure and size provide a framework for discussing how the structure of a course affects the implementation of new ideas.

The framework in this paper is designed to provide a basis for discussions that involve scaling courses. Faculty seeking to scale their courses should identify which course model they are using and determine whether increased enrollment requires them to change course models. Faculty seeking to collaborate on a course arrive a clear consensus of the type of classroom model they will be using. The descriptions of the courses models and discussion of the challenges and resources needed provide a helpful start to planning and/or to seeking additional resources from the college or university. Having a common framework for discussing course models is also helpful for describing pedagogical research and determining how easily a new pedagogical approach can be adopted in a course. The benefits of a common framework increase as the framework is used and sharpened. Ideally this paper will provide a starting point for a continued discussion on classroom models.

A key premise of this paper is that innovation is happening. With the right support and framework to develop models of scaling these innovations can be successfully adopted by faculty at other universities. To return to the business analogy; businesses know that great research does not necessarily lead to great products. A concerted effort must be taken to ensure that great ideas are recognized, developed, polished, and challenges with production at scale are overcome. We hope this framework is a first step in implementing a research to product pipeline in the field of engineering education.

Acknowledgements
The authors would like to thank the National Academy of Engineering for hosting their annual Frontiers of Engineering Education (FOEE) workshop. The ideas in this paper were developed at the 2016 workshop.

References

1. Dewey, J. (1938). *The theory of inquiry*. New York: Holt, Rinehart & Wiston.
2. Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and

learning. *Journal of research in science teaching*, *2*(3), 176-186.
3. Vygotsky, L. S. (1986). Thought and language (Newly revised and edited by Alex Kozulin). *Massachusetts: The Massachusetts Institute of Technology*.
4. Alexander, P. A. (1996). The past, present, and future of knowledge research: A reexamination of the role of knowledge in learning and instruction. *Educational Psychologist*, *31*(2), 89-92.
5. Bransford, J., Vye, N., Stevens, R., Kuhl, P., Schwartz, D., Bell, P., ... & Roschelle, J. (2006). Learning theories and education: Toward a decade of synergy. *Handbook of educational psychology*, *2*, 209-244.
6. Rogoff, B. (1998). Cognition as a collaborative process. Handbook of child psychology: Volume 2: Cognition, perception, and language. Damon, William (Ed)., (pp. 679-744). Hoboken, NJ, US: John Wiley & Sons Inc.
7. Scardamalia, M., & Bereiter, C. (2006). Knowledge building. Theory, pedagogy, and technology. *Cambridge Handbook of the Learning Sciences*. Cambridge, UK: Cambridge University Press.
8. Wittrock, M. C. (1974). Learning as a generative process 1. *Educational psychologist*, *11*(2), 87-95.
9. Biggs, J. B. (2011). *Teaching for quality learning at university: What the student does*. McGraw-Hill Education (UK).
10. Higgins, R., Hartley, P., & Skelton, A. (2002). The conscientious consumer: Reconsidering the role of assessment feedback in student learning. *Studies in higher education*, *27*(1), 53-64.
11. Du, X. Y. (2006). Gendered practices of constructing an engineering identity in a problem-based learning environment. *European Journal of Engineering Education*, 31(01), 35–42.
12. Geisinger, B. N., & Raman, D. R. (2013). Why they leave: Understanding student attrition from engineering majors. *International Journal of Engineering Education*, *29*(4), 914.
13. Godwin, A., & Potvin, G. (2015). Fostering female belongingness in engineering through the lens of critical engineering agency. *International Journal of Engineering Education*, *31*(4), 938-952.
14. Pierrakos, O., Beam, T. K., Constantz, J., Johri, A., & Anderson, R. (2009, October). On the development of a professional identity: Engineering persisters vs engineering switchers. In *Frontiers in Education Conference, 2009. FIE'09. 39th IEEE* (pp. 1-6). IEEE.
15. Seymour, E. H., & Hewett, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder CO: Westview Press.
16. Borrego, Maura, Jeffrey E. Froyd, and T. Simin Hall. (2010). Diffusion of engineering education innovations: A survey of awareness and adoption rates in US engineering departments. *Journal of Engineering Education*, 99(3), 185-207.
17. Smith, M. L., & Glass, G. V. (1980). Meta-analysis of research on class size and its relationship to attitudes and instruction. *American Educational Research Journal*, *17*(4), 419-433.
18. Jacobs, J. A., & Sax, L. J. (2014). STEM majors, the liberal arts and the great recession. In *American Educational Research Association (AERA) annual meeting. Philadelphia*.

19. Biggs, J. 1999. Teaching for quality learning at university: What the student does, Buckingham: Society for research into higher education, Open University Press.
20. Carbone E. J. Greenberg 1998 Teaching large classes: Unpacking the problem and responding creatively In *To improve the academy* 17 M. Kaplan 311 16 Stillwater, OKNew Forums Press and Professional and Organisational Development Network in Higher Education
21. Ward, A., & Jenkins, A. (1992). The problems of learning and teaching in large classes. *Teaching Large Classes in Higher Education, How to Maintain Quality with Reduced Resources* (Ed. G. Gibbs), London: Kogan Page, 23-36.
22. Gallup (Firm) Purdue University. (2015). Great jobs, great lives: the relationship between student debt, experiences and perceptions of college worth. Retrieved from http://www.gallup.com/services/185924/gallup-purdue-index-2015-report.aspx
23. Gibbs, G. (1992. "Control and independence". In *Teaching large classes in higher education: How to maintain quality with reduced resources*, (Ed. G. Gibbs), London: Kogan Page, 37-59.
24. Li, P., & Toderick, L. (2015, June), *An Automatic Grading and Feedback System for E-Learning in Information Technology Education* Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.23518
25. Chang, M., & Downey, A. (2008, June), *A Semi Automatic Approach For Project Assignment In A Capstone Course.* Paper presented at 2008 Annual Conference & Exposition, Pittsburgh, Pennsylvania. https://peer.asee.org/4116
26. Ramachandran, L., & Gehringer, E. F. (2012, June), *Automatic Quality Assessment for Peer Reviews of Student Work.* Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. https://peer.asee.org/21005
27. Nguyen, D. M., Hsieh, Y. C. J., & Allen, G. D. (2006). The impact of web-based assessment and practice on students' mathematics learning attitudes. *The Journal of Computers in Mathematics and Science Teaching*, *25*(3), 251-279.
28. Lueddeke, George R. (1997). Training Postgraduates for Teaching: considerations for programme planning and development. *Teaching in Higher Education*, *2*(2), 141-151.
29. Churchill, N.C., & Lewis, V.L. (May 1983). The Five Stages of Small Business Growth. *Harvard Business Review*. Retreived from hbr.org/1983/05/the-five-stages-of-small-business-growth
30. Chen, X. (2014). *The composition of first-year engineering curricula and its relationships to matriculation models and institutional characteristics* (Doctoral dissertation, Purdue University).
31. Staley, O. (2016, August 22). Harvey Mudd took on inequality and now has more women than men in computer science. *Quartz*. Retrieved from qz.com/730290/harvey-mudd-college-took-on-gender-bias-and-now-more-than-half-its-computer-science-majors-are-women/
32. Yoder, B. L. (2015). Engineering by the Numbers. *American Society for Engineering Education*. Retrieved from www.asee.org/papers-and-publications/publications/college-profiles/15EngineeringbytheNumbersPart1.pdf
33. Hill, C., Corbett, C., & St Rose, A. (2010). *Why so few? Women in science, technology, engineering, and mathematics*. American Association of University Women. 1111

Sixteenth Street NW, Washington, DC 20036.
34. Fast Facts: Harvey Mudd College. Retrived from https://www.hmc.edu/about-hmc/fast-facts/
35. Trow, M. (1996). Trust, markets and accountability in higher education: A comparative perspective. *Higher Education Policy*, *9*(4), 309-324.
36. Monks, J., & Schmidt, R. M. (2011). The impact of class size on outcomes in higher education. *The BE Journal of Economic Analysis and Policy*, *11*(1), 1-17.
37. Acs, Z. J., & Audretsch, D. B. (1987). Innovation, market structure, and firm size. *The review of Economics and Statistics*, *69*(4), 567-574.
38. Benton, S.L., & Pallett, W.H. (January 29, 2013). Class Size Matters. *Inside Higher Education*. Retrieved from www.insidehighered.com/views/2013/01/29/essay-importance-class-size-higher-education
39. McDaniel, E. A., & Colarulli, G. C. (1997). Collaborative teaching in the face of productivity concerns: The dispersed team model. *Innovative Higher Education*, *22*(1), 19-36.
40. Shannon, D. M., Twale, D. J., & Moore, M. S. (1998). TA teaching effectiveness: The impact of training and teaching experience. *The Journal of Higher Education*, *69*(4), 440-466.
41. Pentecost, T. C., Langdon, L. S., Asirvatham, M., Robus, H., & Parson, R. (2012). Graduate teaching assistant training that fosters student-centered instruction and professional development. *Journal of College Science Teaching*, *41*(6), 68-75.
42. Abbott, R. D., Wulff, D. H., & Szego, C. K. (1989). Review of research on TA training.*New directions for teaching and learning*, *1989*(39), 111-124.
43. Buckley, F. J. (1999). *Team teaching: what, why, and how?* Sage Publications.
44. Quinn, S. L., & Kanter, S. B. (1984, December). Team Teaching: An Alternative to Lecture Fatigue. In *Innovation Abstracts*, *6*(34), p. N34.
45. Saiz, M. (2014). Economies of Scale and Large Classes. *Thought & Action*, 149-159.
46. Geske, J. (1992). Overcoming the drawbacks of the large lecture class. *College teaching*, *40*(4), 151-154.
47. Coase, R. H. (1937). "The Nature of the Firm". *Economica*, *4*(16), 386–405. doi:10.1111/j.1468-0335.1937.tb00002.x
48. Shell, Amy E. (2002). The Thayer Method of Instruction at the United States Military Academy: A Modest History and a Modern Personal Account, *Problems, Resources, and Issues in Mathematics Undergraduate Studies*, 12:1, 27-38.
49. Kay, D. G. (1998, March). Large introductory computer science classes: strategies for effective course management. In *ACM SIGCSE Bulletin, 30*(1), 131-134.
50. Kanter, R. M. (2003). *Challenge of organizational change: How companies experience it and leaders guide it*. Simon and Schuster.
51. Gilbert, S. (1995). Quality Education: Does Class Size Matter? *CSSHE Professional File*. Winter, n14, p. 7.
52. Douglas, K. A., Mihalec-Adkins, B. P., Hick, N., Diefes-Dux, N., Bermel, P., & Madhavan, K. (2016, June). Learners in advanced nanotechnology MOOCs: Understanding their intention and motivation. In *123rd Annual Conference of the American Society of Engineering Education*, 26-29.