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Increasing Team Motivation in Engineering Design Courses*

NATHAN J. DELSON
Department of Mechanical and Aerospace Engineering, University of California, San Diego, La Jolla, CA 92093, USA. E-mail: ndelson@ucsd.edu

Team motivation in capstone engineering courses can significantly affect the quality of project outcome. Teams with high motivation often exceed expectations, while less motivated teams at times fail to reach the potential of even a subset of their members. Successful teams typically exhibit a high level of independence in decision making and engineering implementation. However, many components of traditional classroom settings and student projects can hinder team motivation. Moreover, some experiences with student teams have been counterintuitive; groups with slow or rocky starts may end up with higher levels of achievement, while heightened instructor interest in a project topic may result in a detrimental effect on student work. Team motivation is specifically addressed by research in the area of organizational behavior and group processes. This article will apply some lessons derived from group process research to the objective of increasing motivation in student design projects. Relevant input is provided in the areas of project selection, role of instructor, sources of feedback, independence of groups and stages of team development. In addition, familiarity with group processes can increase the quality of the instructor's experience during the inevitable turmoil associated with ambitious student projects. Examples of successful and less successful mechanical engineering capstone design projects are presented to illustrate how team development affects the engineering outcome.

INTRODUCTION

CAPSTONE ENGINEERING courses are offered in the fourth year of a Bachelor of Science degree. Increasingly, capstone courses require student teams to address open-ended engineering problems, and develop working prototypes. Such hands-on capstone courses can provide invaluable real world experience in an environment that emphasizes learning from the design process. However, there is also the potential for a greater let-down if hardware objectives are not met. Not only do students feel disappointment if they do not meet their objectives, but additionally an opportunity has been lost for the class to learn from their hardware's performance. Indeed, it is often during the testing and evaluation phase of a project that students learn problem-solving skills associated with redesign, and can assess first-hand how the hardware performance compares to their theoretical predictions. (Some may question why redesign is formally incorporated into the curriculum, rather than teaching students to 'get it right the first time'. My response is that removing iteration from the design process is possible only in cases whre an existing design is being marginally optimized, and not in the development of new designs. Due to the importance of developing new designs, capstone design courses should emphasize how to proactively manage the iterative nature of the design process, including learning from hardware performance and redesign.) Thus, the increased emphasis on implementing real engineering projects in the classroom raises the stakes for both success and failure [5].

This article presents observations made during four years spent teaching a capstone engineering design course in Mechanical Engineering at Yale University. At this point, these observations are not backed by a statistically validated study. Rather, they represent my own subjective viewpoint regarding effective strategies for increasing student motivation and team cohesion in this kind of course. From the first, I noticed that team motivation dominated project performance, and seemed to have a bipolar distribution that varied between high and low, both between student teams, and within individual teams over the duration of the course. The dominant effect of team motivation on project performance increased my interest in **organizational behavior**, and eventually led me to enroll in a course called Group Processes given by the University of Pennsylvania Graduate School of Education. This course emphasized learning about groups through experiencing actual group processes. Much of what I learned could be quantified as 'common sense'. However, after taking this course I recognized that much of this 'common sense' can be easily forgotten by both students and teachers in a typical classroom setting. In this article, I present how research in organizational behavior has helped me to interpret some of the phenomena I observed while instructing engineering design courses, and my thoughts

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on how to increase the probability of success on student team projects.

CHARACTERISTICS OF AN EFFECTIVE TEAM

Katzenback and Smith [3] distinguish between high performance teams and work groups in which members work congenially together but whose overall performance is significantly less strong. They indicate that in the typical industry environment, most individuals function as part of a work group, rather than in highly effective teams. Yet, the same research indicates that 'true teams' are responsible for many technical innovations and breakthroughs. My own observations leads me to believe that while 'true team' behavior may be rare in a typical industry setting, an academic environment is well-suited to the formation of highly motivated teams. For many students, a capstone design project represents their first opportunity to manage an engineering project with a substantial budget; an opportunity they have been anticipating for four years. Moreover, students need not feel concern or pressures related to job security, which can hinder successful team performance in industry. Thus, academia provides an atmosphere highly conducive to the formation of strongly motivated teams. Yet, instructors must keep in mind that it is easy to inadvertently squelch student enthusiasm.

Katzenback and Smith conclude that highly motivated teams focus on project objectives and take responsibility for achieving these objectives. I have noticed the following characteristics of student design teams with high levels of motivation and achievement:

- Team takes responsibility for decision making and achieving project objective.
- The project objective becomes more important than the course grade.
- Obstacles are treated as challenges to be overcome, rather than reasons for project failure.
- Resources outside of the classroom are utilized.
- Significant time is committed to the project.
- Constructive disagreements between team members.
- Team regards instructor as source of design expertise and not as the decision maker.

Creating an environment which encourages students to take responsibility for decision making can be at odds with the traditional classroom setting where the instructor is the authority figure. The first step in creating such an environment is selecting an appropriate engineering design project.

PROJECT SELECTION

The topic of the engineering project is critical for team motivation because the team will not be motivated unless the students see 'a specific performance challenge that is clear and compelling to all team members' [3]. In addition, the student team must believe that it has the capacity to successfully achieve all objectives.

In the Yale capstone course, the instructor selects the design projects, which are often sponsored by industry. Due to the importance of the topic of the engineering project, significant instructor effort is spent on identifying projects that are achievable within the time and budget constraints of the course, and whose results can be applied in a meaningful way in the real world. A detailed discussion of selection criteria often used can be found in Caenepeel [2] and King [4]. The key selection criteria used in the capstone course are:

- an achievable hardware objective;
- room for creativity in the design solution;
- an external source of feedback (in addition to faculty);
- meaningful intermediate milestones can be defined.

Note that all engineering projects have intermediate objectives that can be met. However, due to technical or budgetary reasons, with certain projects it is not possible to get meaningful performance measurements midway through the project. While such projects may be viable engineering projects, I have found that they do not provide the best educational experience. A common intermediate milestone is to verify the performance of the high risk components of a design concept.

While project selection is very important, a 'good' topic alone does not guarantee high team motivation. Indeed, a project which technically has high potential for a meaningful real world contribution and whose objectives are compelling to the instructor, may not be viewed as such by the students at the onset of the project. Additionally, students who are tackling their first design project may not have confidence in their own ability to achieve the project objectives, even when the objectives are achievable. Thus, project selection is a good start, but other course implementation issues as described in the following also affect team motivation.

This article addresses course implementation issues that can affect team motivation, presented in the context of the ME489 capstone design course at Yale University. In this one semester course, student teams of three to six members tackle open-ended design problems and develop working prototypes. The course content guides the students through the design process and addresses topics such as problem definition, concept generation, concept selection, project management, risk reduction, redesign, and detail design. In the last section of this article, examples of successful and less successful projects completed for ME489 are presented with a description of both the group process and level of team motivation.

DEVELOPMENT OF TEAM INDEPENDENCE

In the traditional classroom setting, the instructor represents the ultimate source of subject knowledge, and provides incentive to learn in the form of a grade. However, the generation of high performance teams requires a shift in this paradigm [3]. This transition is not always easy for students. High team performance requires each team to take responsibility for their project outcome, requiring them to feel a sense of independence from the instructor. In order to encourage this independence, I have found it helpful for the instructor to purposely withdraw from the decision making process, while remaining available to provide design suggestions. Decisions related to budget allocation and design direction are left largely to students. Observing students struggle with their new-found freedom and lack of direction can be disconcerting for the instructor. However, ultimate familiarity with the typical stages of team development helps put these behaviors in perspective.

Bennis and Shepard [1] describe the typical phases which groups progress through. Not all teams progress through these stages linearly. Some teams may not progress through all of the stages, and others may transition quickly through a certain stage or revert backwards. Listed below are three early stages of team development which are common in semester-length student design projects. The final stage, 'Resolution,' provides for high productivity and creativity within the team, and is thus the objective for open-ended design tasks.

Dependence (forming)

During this initial phase, team members look to the instructor to make design decisions for them (which the instructor purposefully refuses to do). This phase is also referred to as 'forming', since the students focus on developing a level of comfort and trust with each other, which may cause them to hesitate in voicing disagreement regarding design decisions. While establishing trust between team members is essential from the outset if a team is to take on ambitious design problems in the future, the practice of avoiding even constructive disagreement among team members could prevent all design alternatives from being considered by the group, thereby reducing the potential for creative problem solving. Emphasis on maintaining a level of comfort among team members often results in a lack of initial team effectiveness. Subsequent frustration with the lack of effectiveness during this stage provides an impetus for moving on to the next stage. Students who do not have experience with open-ended design problems may have more difficulty at first in coping with lack of instructor leadership, but these students often display the highest potential for growth during the class. Meetings with the instructor at this stage often have low productivity, with few decisions being made. It is during this stage that team building exercises are likely to be most effective. If the forming stage is rushed through too quickly, then personal relationships may not have time to develop sufficiently to support challenging teamwork in the future. An instructor may be concerned about lack of project progress during this phase, but important team foundations are being developed. This can be seen in the 'Steam Screen for Movie Projection' project described later in this paper.

Counterdependence (storming)

The second phase, 'counterdependence' or 'storming,' results directly from the refusal of the instructor to make decisions for the student teams, and can be characterized by the students' subtle rebellion against the authority of the instructor as they begin to take responsibility for the future of their projects. For example students may show up late to meetings with the instructor or complain about the design project. Signs of rebellion can initially be quite disconcerting for the instructor, yet when viewed in context to group processes the rebellion indicates that the team is taking responsibility for the project success, and thus becomes much easier to understand and accept gracefully. The instructor can always use their authority and power as grade provider to squelch manifestations of rebellion, however, this may prevent the transition to the more desirable stage of 'resolution'. The counterdependence stage stimulates a high level of team motivation, and 'rebelling' against the authority figure can serve to galvanize the team into a cohesive unit. However, overall engineering effectiveness suffers during this phase, since the team feels inhibited in seeking guidance from the instructor. Meetings between teams and the instructor at this stage may involve student disagreement with the instructor's ideas. Evidence of this phase can be seen in both the 'Wheelchair Mounted Door Opener' and 'Jar Opening Kitchen Appliance' student projects later described.

Resolution (performing)

During the third phase, 'resolution' or 'performing,' team members focus on project performance and the team functions at its peak level of effectiveness. The student team has taken ownership of the project, and is comfortable soliciting the instructor's input without the fear that the team's decision-making capacity will be usurped. Team members have passionate and constructive debates about design decisions, and thereby incorporate the expertise of all members into their decisions. Meetings with the instructor are shaped by team project objectives. These meetings can be very short when team members have agreed on what to do next, or involve intense engineering discussion when critical decisions are required. Meetings during the resolution phase are generally quite rewarding for the instructor and students alike.

SOURCES OF FEEDBACK

In engineering design projects in general, feedback from a customer provides critical technical information regarding project specifications and evaluation of potential design solutions. Such feedback may come from a sponsoring company or from end-users of the product. While all student projects require a source of feedback for technical purposes, I find that the source and quality of this feedback significantly affects student team motivation. Specifically, students benefit greatly from feedback throughout their design process that is NOT from the instructor. An external source of feedback helps shift the paradigm of their projects from the traditional classroom exercise to a 'real world' design opportunity. External feedback provides a valuable alternative to the expertise of the instructor, thereby helping students transition away from depending too much on the instructor (or treating their course grade, rather than the project objective, as the ultimate aim of the course).

A temptation exists for instructors to suggest project topics relating to their own research areas. Indeed, university faculty are encouraged to integrate their own research interests in the classroom [7]. The potential for saving research time makes the prospect of doing so especially attractive. However, I find that with design projects in the instructor's area of expertise, team independence often develops more slowly and performance suffers. Perhaps the instructor possesses so much detailed knowledge regarding project specifics that students do not feel confident in making decisions on their own. Additionally, it may be difficult for the instructor to relinquish the role of decision-maker for a project in which he or she has a high stake in the outcome. (See Robot programming example later in this paper.) In either case, there exists little room for student independence and creativity. Thus, while I believe that student design projects in the instructor's research area have potential for success, it is important to structure the project in a fashion that encourages team independence to develop.

Overall the quality of customer feedback should be evaluated in terms of both its technical content and its affect on team motivation. High quality feedback increases the significance of the engineering problem being addressed in the eyes of the student team members, thus helping to create the 'compelling performance challenge' necessary for high team motivation. Good results have been achieved when feedback was available both from a sponsoring company and potential end-users of the product. End users who do not 'need' a new design solution may provide valuable product information but may not be overly enthusiastic about a potential future solution, while a sponsoring company with a stake in the outcome typically shows a high level of interest in project progress. On the other hand, end-users with a vested interest in the outcome can provide sufficient motivation for student teams alone, as in the case of the 'Wheelchair Mounted Door Opener' project described later.

DEADLINES AND CRISES

In both individual and team projects, deadlines and intermediate milestones are important components of project management. However, within team projects, deadlines can also serve to stimulate team development. Katzenback and Smith advocate building team motivation by going for 'small wins and large wins simultaneously,' an approach I endorse wholeheartedly. Successful accomplishment of an intermediate goal builds team confidence in their collective ability to achieve larger objectives. There is an advantage in intermediate milestones even for a team that does not perform well at a given milestone. Of course it is desirable that all teams in the class successfully accomplish their intermediate objectives. However, I find that as long as a majority of the teams in a class have high quality presentations, deadlines will help the less successful teams as well. Often, initially weaker teams rise to the top in later milestones, due both to the students' desire to demonstrate their ability to their peers, and to their increased belief in student capability (which they gain by observing more successful student teams).

Invariably, approaching milestones often leads to crises as the team struggles to meet deadlines. While it may be tempting for an instructor to relax a deadline to accommodate hard working students, the crises these deadlines create can actually have a beneficial effect on team motivation. Groups often reach defining moments in which they cohere to form true 'teams' (Bennis and Shepard [1]). Rising to meet the challenge of an intermediate deadline can be such an event. The deadline also provides a justification for team members to demand peak performance from each other. When a team successfully rises to meet the challenge of an intermediate objective, trust is developed regarding commitment to the project. This trust is an essential ingredient for achieving more ambitious project objectives. Thus, adherence by the instructor to achievable deadlines may not be popular among students, but actually helps team members motivate to complete the task.

While it may appear obvious for an instructor to require intermediate deliverables in a design class, the Organization Behavior benefits provide additional incentives for maintaining rigor in these requirements. The intermediate milestones used for this class are:

1. Problem definition presentation.
2. Concept generation and selection.
3. Risk reduction test.

4. Proof of concept test.
5. Final design review.
6. Final presentation (and redesign).

The preceding two sections describe how the traditional design tools of intermediate objectives and customer feedback can also be used for team development. While the dual role of these tools are helpful, I have also experimented with classroom exercises that are used solely for the purpose of team building as described below.

TEAM BUILDING EXERCISES

Team building exercises alone cannot create solid team motivation. However, early in team formation, these exercises can serve to break the ice and assist the process of establishing a rapport and trust among team members. In addition, the exercises and accompanying discussion about organizational behavior serves to increase awareness about the significance of group dynamics in any team project. A number of team building exercises borrowed from organizational behavior material were initially incorporated into ME489, including building packaging to protect an egg which was then dropped off a ledge, and an exercise where the team had to prioritize its activities during a hypothetical earthquake disaster.

While these original team building exercises did achieve much of their intended function of breaking the ice and increasing awareness of team dynamics, I decided to redesign them to reflect the effect of teamwork in engineering projects. Specifically, I wanted to illustrate the potential advantages of teamwork for project creativity and idea generation. The original exercises lacked a source of real-time feedback as team dynamics occurred. For example, the quality of the egg packaging was not determined until the end of the project, and the hypothetical nature of the earthquake disaster left room for multiple interpretations.

I developed three exercises, two practical and one theoretical. First, I held a fifteen-minute competition between teams in building a structure of maximum height using a deck of playing cards and a roll of tape. At the culmination of this competition, each team discussed as a group their previous design experience and summer jobs. Finally, students tackled a structure building competition, this time using a package of cream filled cookies. At the completion of these exercises, the whole class reviewed the events in terms of group process theory.

I juxtaposed the exercises as such in order to evaluate whether the discussion exercise would increase the quality of communication and design solutions in the second building exercise. Thus far, I cannot report conclusive results. However, exercises with real-time feedback did give rise to additional phenomena present in many engineering situations. For instance, during the card exercise, one of the teams taped a string of cards together and hung it from the ceiling, which was much higher than any of the other group's towers. This gave rise to the 'not-invented-here' syndrome, as all other teams ignored this obviously better design solution. Only after completion of the contest could I illustrate how one might actually improve upon a competitor's idea (in this case by raising the ceiling tile to heighten the structure), but that human nature often prevents us from doing so. The students' response to this exercise illustrated that lesson much more effectively than I could have in a lecture.

DUAL ROLES IN THE DESIGN PROCESS AND TEAM DEVELOPMENT

To improve the technical decisions made during engineering design projects, specific methods have been developed for managing the design process and increasing engineering efficiency, many of which are described in [6]. This article has identified that some of these design process methods have a dual role, and also serve to increase team motivation. These dual role tools are summarized in the table below. Although one may implement many of these practices solely for technical reasons, I believe that increased awareness of the potential benefit in terms of team development will help one gain insight into (and improve) team performance.

Table 1.

	Engineering benefit	Team-building benefit
Customer feedback	Design objectives are focused on actual need.	Team independence is increased by elevating the project objective over the institution reward structure.
Intermediate milestones	Technical problems are identified early in the design process when they are easy to fix.	Small wins build up team confidence, and the crisis of a deadline can serve to galvanize a team.
Refusal of instructor (or supervisor) to make design decisions	A wider range of design solutions will be considered, increasing the odds for conceptual breakthroughs.	The team rises to fill the 'vacuum' in decision making and takes responsibility for project success.

STUDENT PROJECT EXAMPLES

A number of student project examples are described below in terms of interaction between group processes and engineering implementation. Additional technical details are provided at: http://www.eng.yale.edu/me489/.

Engineering success for an open-ended design problem is not easy to quantify (and the educational content learned by the students even less so). However, one indicator of success is when a team develops and implements a design solution that is superior to any solution initially envisioned by the instructor. I will now describe three student projects which I view as highly successful, and one less successful project. I've attempted to interpret the performance of the teams in terms of group processes. It should be noted that these interpretations of team dynamics are based solely on my subjective observations and opinions as an instructor.

Steam screen for movie projection

The sponsor for this project was the Lincoln Center for Performing Arts in New York, and the sponsor's objective was to project a movie above their rooftops onto jets of steam. The sponsor's contact person was highly motivated, and the student team was enthusiastic. Nevertheless, the project began with a perceived slow start toward the sponsor's objective. The team began by evaluating a number of alternatives to steam as a projection medium, including fabric strips and fabric socks supported by steam. Simple prototypes of these various concepts confirmed the advantage of the initial steam concept. Thereafter, the team proceeded efficiently to develop a functioning steam screen using both theoretical analysis of steam flow and experimental evaluation of projection quality. The final result was a functioning steam screen projected from the top of a Yale building, using a combination of compressed air and power plant steam (exceeding my initial expectation of a small scale proof of concept prototype). From a group process perspective, I believe that the initial 'slow' period was a critical time for team development which allowed the team to assert their ownership over the direction of the project. In addition, the intermediate objective of building alternative prototypes provided the team with small wins, through which they developed their ability to work together.

Wheelchair-mounted door opener

The sponsor for this project, the Center for Disability Rights in New Haven, identified door opening as a high priority objective for wheelchair users. I evaluated the feasibility of the project and identified at least one viable solution, using an extension arm to assist in pushing doors open, thus overcoming the poor mechanical advantage a wheelchair experiences when driving into a door. The student team met with wheelchair users and saw their frustration as they demonstrated their inability to open even simple doors. Motivated by their contact with end-users, the student team chose to tackle the more difficult problem of pulling open a door. However, team progress became bogged down due to this more difficult challenge. The potential extension arm solutions being considered became more bulky, which was a significant drawback as perceived by wheelchair users. This was only my second year as instructor of ME489, hence I responded to the team by advocating more advanced extension arm approaches. The team responded by sending subtle but unmistakable signs of rebellion, which caught me off guard. Nevertheless, the motivation and sense of independence gained by the students during this phase ultimately enabled them to overcome the design obstacle, and develop a new approach. This new approach used a compact cable-driven device which attached to the door handle and pulled the door open from the wheelchair (including an innovative method for twisting the handle open). The final design was a success, and was selected as a finalist in the Institute of Electrical and Electronics Engineers Biomechanics Student Design Competition. I now believe that more appreciation for group processes on my part at that juncture would have reduced frustration for all involved, and in the ensuing years, I changed my approach when tackling similar situations.

Automatic jar opener

The sponsor for this project, Household Projects, Inc., identified a market need for a high end jar opener. Before initiating the project, I evaluated its feasibility and felt that a device that grasped the top and bottom of the jar combined with a twisting mechanism would indeed be feasible. However, in response to the sponsor's input, the team decided to emphasize compactness and developed an approach which grasped the top and sides of the jar. Despite their work on concept generation, progress with developing a prototype was slow. Rather than pressing the students to proceed with specific steps (as I might have done in years past), I chose instead to let a meeting with the project sponsor provide an indicator to the team of their progress. When the frustration level among the team members rose due to their lack of progress, I began to sense signs of rebellion. In response, I chose to further remove myself from group decision making. I indicated to the group that our meetings together were no longer beneficial, and that I would meet with them again only when they had made demonstrated progress, as I'd already provided them with all the suggestions that I had. The team responded by taking responsibility for developing a working prototype, at which point they began consulting with me regarding detail design issues. The project culminated with a high level of team motivation, and their design was selected as a winner of the Inventors' Hall of Fame Collegiate Inventors award. I credit my increased familiarity with group processes for enabling me to maintain distance between myself and a struggling team when it was appropriate to do so.

It is noteworthy that in both the 'Automatic Jar Opener' and 'Wheelchair Mounted Door Opener' projects, student teams were drawn to increasing product compactness, which is a common design objective but which makes it more difficult to achieve a solution. This phenomenon reflects that the students have become motivated by the project itself (beyond the incentive of grades), and ultimately developed more ambitious objectives.

Robot programming by human demonstration in biomedical laboratories

An instructor sponsored project, this involved an application of my own research work in robotics. The project objective was to apply an easy-to-use robot programming method to tasks in biomedical labs. I identified sources of feedback for the project from laboratories in the medical school and with robot vendors. The laboratory personnel were interested in devices that would help make their jobs easier, and suggested the task of pouring augur into Petri dishes, which was monotonous and potentially dangerous due to the potential of spilling hot liquid. However, the project outcome was not a priority for the medical laboratories, since it was unlikely that the design project would produce a 'lab ready' prototype that they could use in the short term future. Other difficulties with this project were related to it falling within my own area of expertise. As it happened, I was the only one involved who was familiar with all details of the programming theory and robot operation. The student team put in a significant amount of effort, and successfully implemented a working prototype that programmed the robot to perform tasks relating to Petri dish preparation. However, the level of team commitment and overall success of the project was demonstrably lower than in the aforementioned examples. In retrospect, I feel that this project would have found greater success with a more committed external source of feedback, and with a technical framework that facilitated team independence from the instructor. While I believe that academic research can provide a fertile source of valuable design projects, in order to foster team independence the relationship between the course instructor and the student design team should be structured to promote student autonomy. *Specifically, there should be less faculty control over the direction that the project takes than in a traditional research project.*

CONCLUSION

Familiarity with organizational behavior theory on group processes provides an excellent resource for developing and improving a capstone engineering design course. Lessons taken from this theory may be applied toward increasing both team motivation and the quality of an instructor's teaching experience. Highly motivated student teams can exceed the instructor's expectations and capabilities. One of the key attributes of a motivated team is that the members identify with the project objectives and this sense of identification can be strengthened through interaction with motivated end-users and company sponsors. Another attribute of an effective team is that the team members believe in their collective potential to achieve high quality results, which may be strengthened within the classroom environment by working toward small wins and large wins simultaneously. Finally, high performing teams take responsibility for their project outcome, which an instructor can encourage by purposely withdrawing from the decision making role while still providing technical and project management expertise. Many of the methods used to increase team motivation also benefit the design process for technical reasons, and their dual role can be utilized for both engineering and team motivation objectives.

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Nathan Delson has recently joined the Department of Mechanical and Aerospace Engineering at the University of California, San Diego as the Director of the Design Center and Academic Coordinator. For the past four years he taught freshmen and senior level design courses at Yale University. Nathan's Ph.D. in Mechanical Engineering is from MIT, where he became interested in design education. His research interests include robotics, biomechanics, and product design. Nathan is also one of the founders of Coactive Drive Corporation, a company that develops actuator technology.