AC 2012-3962: THE GASDAY PROJECT:

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Dr. Ronald H. Brown is Associate Professor of Electrical and Computer Engineering at Marquette University and the founding Director of Marquette University's GasDay Project. Dr. Brown's research is in system modeling, identification, prediction, optimization, and control. The applications of his research has been focused on natural gas distribution and transmission since 1993, when the GasDay Project was founded as a means to connect students with the many industrial partners who support the lab's work. Over the course of the project he has worked with more than 150 undergraduate students from four colleges at Marquette directly participating in the project, and many more who have participated through classroom assignments that have "borrowed" project ideas from GasDay. He is a frequent presenter at energy industry meetings and consultant to many energy companies looking for guidance in planning for daily and peak load conditions.

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Mr. Thomas Quinn is the Director of Business Operations for Marquette University's GasDay Project and Adjunct Associate Professor of Electrical and Computer Engineering at Marquette. He develops and manages the GasDay Project's partnerships with the many energy companies across the U.S. that sponsor the project's research and license its software products. He graduated with a B.S. in Computer Science from Marquette University (Milwaukee, WI) and an M.S. in Computer Science from Rensselaer Polytechnic Institute (Troy, NY). Prior to joining Marquette University he was the Director of the Emerging Technologies Group at Compuware Corporation, and Vice President for Business Development at the Gecko Group. Mr. Quinn serves on the Executive and Academic committees for the Green Energy Summit, an annual international conference on sustainable energy innovation and investment.

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Dr. Mark Nagurka is an Associate Professor of Mechanical and Biomedical Engineering and the Lafferty Professor of Engineering at Marquette University. He earned his B.S. and M.S. in Mechanical Engineering and Applied Mechanics from the University of Pennsylvania and a Ph.D. in Mechanical Engineering from M.I.T. Prior to joining Marquette he taught at Carnegie Mellon. Dr. Nagurka is a dedicated educator and active researcher with interests in mechatronics, system dynamics and design, human-machine interaction, and engineering pedagogy. He is a registered Professional Engineer, a Fellow of ASME, and a former Fulbright Scholar.

The GasDay Project at Marquette University:
A Learning Laboratory in a Functioning Business

Abstract

The GasDay Project is a working software business within a university in which undergraduate and graduate students apply what they have learned in the classroom to create and license a product that solves a real-world problem. Multidisciplinary teams of engineering, mathematics, computer science, and business students produce software licensed by U.S. utilities to forecast over 20% of the nation's daily natural gas demand.

The GasDay Project functions as an extracurricular learning laboratory that incorporates several student-centered learning methods including active, collaborative, and project-based learning. It provides students with experiential learning opportunities similar to those associated with co-op, internship, and research experiences. Students learn about entrepreneurship, teamwork, and dealing with customers, which prepare them for successful careers.

This paper describes the pedagogical approaches to student learning employed by the GasDay Project as well as the educational benefits to students including (*i*) hands-on learning in a business setting with real-world consequences for successes and failures, (*ii*) direct contact with customers and industrial partners, (*iii*) experience with project management and the importance of working in a setting with competing priorities that must be met with a fixed set of resources, and (*iv*) knowledge of how research is conducted and how to take it from the laboratory to the marketplace.

Introduction to Student-Centered Learning

In traditional college teaching, most class time is spent with a professor lecturing and students watching, listening, and writing. Students work individually on assignments, and cooperation is generally discouraged. Student-centered teaching methods shift the focus of activity from the teacher to the learners.

Student-centered learning has been shown to be superior to teacher-centered instruction, a conclusion that applies whether the assessed outcome is short-term mastery, long-term retention, depth of understanding of course material, acquisition of critical thinking or creative problem-solving skills, formation of positive attitudes toward the subject being taught, or level of confidence in knowledge or skills.[1] These methods include active, collaborative, cooperative, and inductive learning.

Active learning is an instructional method that engages students in the learning process. In active learning students conduct meaningful learning activities and think about and are connected to what they are doing. While this definition could include traditional activities such as homework, in the education literature active learning most commonly refers to activities that are introduced in the classroom. The core elements of active learning are activities that engage students. Active learning is often contrasted to the traditional lecture format where students passively receive information from an instructor.[2]

The more active students are in the classroom, the more engaged they are in the learning process and the more they remember. Edgar Dale's "cone of learning," shown in Figure 1, suggests that student retention, as measured two weeks later, depends on the level of active learning. Classroom activities simulating a real experience or "doing the real thing" involve students the most in the learning process and result in them remembering up to 90% of what instructors do and say.[3]

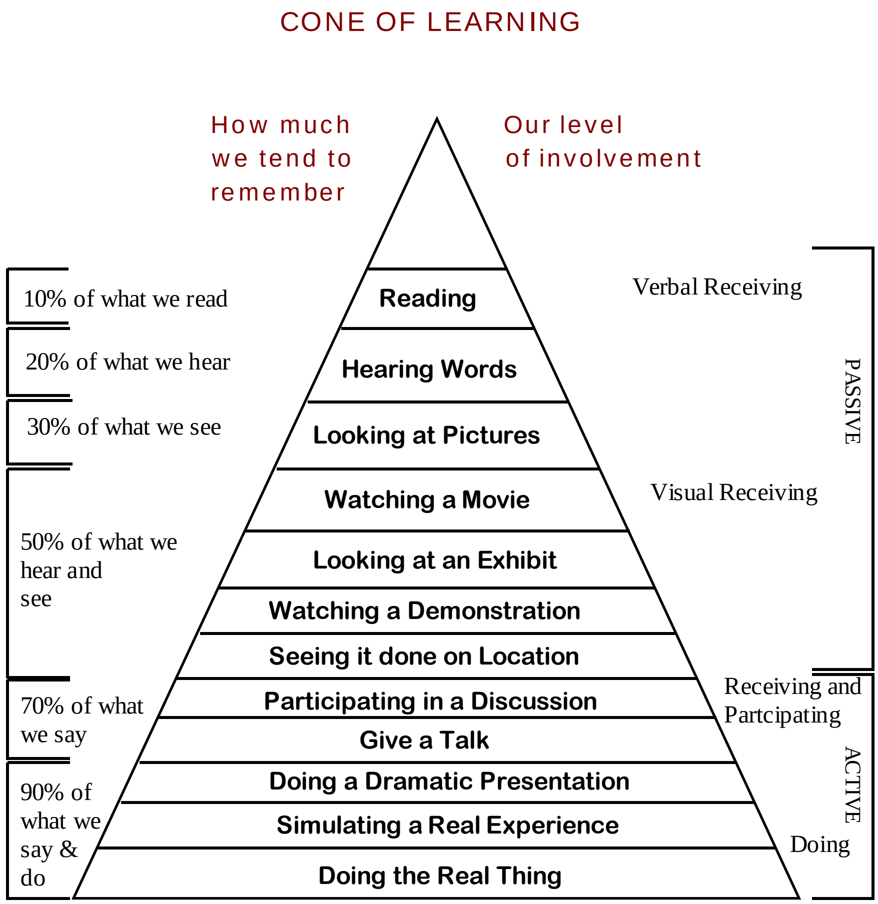

Figure 1: Cone of learning (www.foundationcoalition.org)
based on Edgar Dale's cone of learning.[3]

Collaborative learning refers to an instructional method in which students work together in small groups toward a common goal. As such, collaborative learning encompasses all group-based instructional methods, including cooperative learning. The core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity.

Cooperative learning is a structured form of group work where students pursue common goals while being assessed individually. The most common model of cooperative learning includes five specific tenets: individual accountability, mutual interdependence, face-to-face interaction, appropriate practice of interpersonal skills, and regular self-assessment of team functioning. The common core element among models is a focus on cooperative incentives rather than competition to promote learning.

In inductive learning students are presented with challenges (questions or problems) and then allowed to learn the course material in the context of addressing the challenges. Inductive methods include inquiry-based learning, case-based instruction, problem-based learning, project-based learning, discovery learning, and just-in-time teaching. Problem-based learning involves introducing relevant problems at the beginning of the instruction cycle to provide the context and motivation for the learning that follows. It is always active and usually collaborative or cooperative and typically involves significant amounts of self-directed learning on the part of the students.[4,5]

Value of Student-Centered Learning for Career Preparation

Undergraduate engineering programs strive to prepare students to be successful engineers. Shortly after beginning their careers, engineering graduates soon realize that the best engineering decisions are not always the best business decisions, and vice-versa. Cost, scalability, competitiveness, and other issues often force compromises of what might otherwise be the most elegant engineered solutions possible. Less experienced engineers might be unfamiliar with how solutions are designed to meet multiple, often non-technical, objectives, as well as customers with their own wants and needs, business objectives, and varying levels of competency and available technical support. Many, if not most, engineers were not exposed to these situations during their education. Delivering and supporting well designed products into customers' hands to generate value for their businesses requires skills that some engineers may not have developed in college.

Undergraduate engineering programs offer several opportunities beyond the classroom to help prepare engineering students for workplace realities. The most notable of these are co-operative (co-op) engineering programs. There are other forms of internships, industry-sponsored research projects, and various university-industry collaborations that help young engineering students develop new skills and apply knowledge learned in the classroom to the workplace environment.

Examples of Student-Centered Learning at Undergraduate Institutions

The following are examples of student-centered learning activities/programs at U.S. undergraduate institutions:

University of Delaware

According to the University of Delaware website (http://www.ugs.udel.edu/DLE/) all students are required to participate in a Discovery Learning Experience, defined as experiential learning that involves instructional experiences (out-of-class and beyond typical curriculum courses). These enrichment experiences for students occur under the supervision of a faculty member. Discovery Learning Experiences include internship, service learning, independent study, undergraduate research, and study abroad.

University of Colorado

The Discovery Learning Program at the University of Colorado enables students to develop critical thinking, problem solving, and research skills while sharing fresh perspectives as members of integrated research teams. The learning model established by Colorado's College of Engineering and Applied Science creates collaborative teams involving undergraduate and graduate students, faculty, and industrial partners. This advances student learning through an inquiry-based approach that complements the academic curriculum.

Rose Hulman Institute of Technology
At Rose Hulman, student-centered learning occurs in extracurricular projects and in-class, hands-on experiences. Student teams work on competitive project teams for the Eco-Car, Formula SAE, Human Powered Vehicle, and the design/build/fly AIAA national student design competitions. Students do not receive credit for these activities. Faculty mentors and team advisors volunteer their time to work with the students on these projects. The school provides a budget of at least $10,000 per project, space to work, and access to test facilities (e.g., wind tunnel, composite testing, and other facilities). In addition to extracurricular projects, students are engaged in in-class activities such as fluids laboratory demonstrations and projectile motion modeling, measurement, and validation experiments ending with an in-class competition.

Marquette University
Student- centered learning within Marquette's College of Engineering includes in-class and extracurricular activities that allow students to learn by doing and to apply what they have learned throughout the engineering curriculum. In-class activities include hands-on demonstrations, field trips, case studies, student projects and presentations, design competitions, laboratory experiments, and other activities. Extracurricular activities include student design projects for national student design competitions, co-op and internship experiences, and other activities that provide opportunities for students to "learn by doing". All of these activities require students to apply what they have learned in a specific class and in other classes throughout the engineering curriculum.

The Marquette GasDay Project is a highly unique and innovative example that combines many of the student-centered learning methods described earlier. Details of the GasDay Project and its educational benefits are presented in the following sections.

GasDay Project History

Marquette University's GasDay Project licenses a natural gas demand software application to 28 natural gas utilities around the United States. On a typical day GasDay software installed at those utilities forecasts over 20% of the nation's natural gas demand. The models and software application are developed by undergraduate and graduate engineering students at Marquette, under the supervision of faculty members and a business manager.

The GasDay Project was initiated in 1993 by Ronald Brown, Ph.D., as a research project funded by the Wisconsin Gas Company. Additional funding came from the Wisconsin Center for Demand Side Research, and then from the Gas Research Institute (GRI), a natural gas industry collaborative. That effort produced promising research results and the first forecasting models used by the Wisconsin Gas Company in Milwaukee, WI (now part of We Energies). After a brief partnership with an outside firm, Marquette began licensing GasDay directly to natural gas utilities in 2001.

The GasDay Project is one of the largest research and technology transfer activities at Marquette University. It remains within the Department of Electrical and Computer Engineering, part of Marquette's College of Engineering. GasDay is self-funded from licensing revenue and research grants. The revenue generated by the project provides Marquette undergraduate and graduate students with opportunities for research, a source of financial aid, and hourly employment. GasDay revenue also generates royalty income for Marquette University.

GasDay licensable technologies are the result of the commercialization of GasDay's laboratory research. Students are involved in every step of this process – from participating in the research, to implementation and testing of new features, to final delivery and customer support activities. As of January 2012, over 180 students have participated in the GasDay project.

Educational and Other Benefits of GasDay Project Activities

Research Laboratory – The GasDay Project conducts ongoing research into energy demand and modeling techniques. This provides a rich and contemporary set of topics for graduate student research towards master's theses and doctoral dissertations. Research is funded by direct sponsorship of industrial partners and by GasDay product license fees. The results of this research are disseminated as licensed software and research reports for customers and as more traditional academic journal articles and conference presentations.

Educational Laboratory – The GasDay Project regularly hosts course-related student projects, providing students with the opportunity to work directly with some of the largest energy companies in the U.S. Many of the projects are incorporated in the College of Engineering's multidisciplinary senior capstone design course, where student teams work for a full academic year on a project of direct interest to a GasDay industrial sponsor. Other courses with students undertaking GasDay projects come from the College's Engineering Management program and from the Department of Mathematics, Statistics, and Computer Science. Approximately fifteen students participated in four GasDay Lab student projects over the last academic year.

Technology Transfer Center / Student Employment Site – Marquette University licenses GasDay software applications and mathematical forecasting models to energy companies. Marquette students participate in all aspects of this business, including software development and testing, data analysis and modeling, marketing, and customer support. This activity generates significant revenue used to fund part-time employment opportunities and graduate student support. Over the last academic year the GasDay Project provided the following student financial support:

- assistantships for five graduate research assistants in the College of Engineering, one from the Department of Mathematics, Statistics, and Computer Science, and two from the Graduate School of Management
- hourly employment for eleven undergraduate students from the College of Engineering and two from the College of Business Administration
- hourly employment for one high school student, who plans to study engineering in college, participating in a Marquette Engineering Outreach program.

Industrial Outreach Center – Over the course of a typical year, the GasDay Project interacts with approximately thirty companies working in energy or related industries. GasDay conducts on-site visits and teleconferences, and hosts several companies who visit Marquette University. GasDay also helps organize the Gas Forecasters Forum, an industry conference held each fall as part of the Southern Gas Association's Fall Leadership Conference.

GasDay Project Activities

There is an annual cycle to the business of GasDay that makes it well-suited for student participation. Not surprisingly, this cycle is based on the timing of the heating season in North America. Natural gas utilities spend the summer and early fall each year preparing for the upcoming heating season, as does GasDay. The fall is the busiest time of year at GasDay as students prepare software deliveries for gas utility customers.

Research leading to new model development ideas is ongoing. Each fall GasDay prepares a significant software release timed to coincide with the onset of the heating season. Early each spring, faculty and students jointly determine which model improvements to implement in GasDay product software. At the same time, a separate team of students develops a work plan for software implementation of the features and improvements for the fall release. The combined teams set milestone dates for intermittent "alpha" and "beta" releases, software testing, integration testing, and mock customer deliveries for practice. All this work culminates in deliveries of new GasDay configurations sent to customers throughout the fall season.

Every GasDay delivery is a custom configuration specific to a utility's natural gas distribution system. Most utilities are comprised of multiple energy distribution regions, or *operating areas*. GasDay students train custom models for each individual operating region and then merge those models with the current release of GasDay application software. Every integrated configuration is tested and packaged for installation at the customer site.

GasDay-Related Student Research Topics

The subject of most graduate students' research is related to improvements to the GasDay forecasting models, or the various treatments of the data used to train those models. Examples of these topics include:

- investigations into methods to build forecasting models for non-stationary systems
- improved detection and treatment of outliers in natural gas daily or hourly flow time series data
- ensemble techniques for combining multiple forecasts

- model frequencies of unusual weather events
- exploitation of high-density weather measurements and forecasts

Ideas generated by student research that provide measurable, consistent improvements to GasDay demand forecasts are implemented each year. This makes it possible for a student in a two-year Master's degree program to propose an idea and see it through from conception to product implementation and delivery to a customer prior to graduation.

Software Development Activities

GasDay's software development team is led by a recent graduate of Marquette's Biocomputing program, who chose to join GasDay as a full-time employee upon graduating. The software development team tends to be staffed by undergraduate students majoring in Computer Engineering, Electrical Engineering, Computer Science, and Biocomputing.

GasDay's software development processes introduce students to many of the tools of the professional programmer and mandate use of many of the practices students encounter in their software engineering coursework such as:

- agile software development techniques, including frequent deliveries of working software, pair programming, team review, and test-driven development.
- frequent collaboration with GasDay customers to improve application usability or to develop new feature ideas. (GasDay is very fortunate to have customers who agree to install beta-version software to evaluate and test new features as they take shape.)
- tools for requirements management, issue management, and automated testing and test reporting.
- software configuration management tools for change control and managed releases.

GasDay student software engineers participate in early-stage idea development through to feature implementation and release to customers. Participation in GasDay software development reinforces the importance of a disciplined and collaborative team approach and gives students an early opportunity to embrace techniques being taught in the classroom.

GasDay Data and Manufacturing Team

The Data and Manufacturing team is comprised of GasDay members who manage and execute GasDay customer deliveries and follow up with customer support. Members of this team range from GasDay's newest students to some of the project's most experienced graduate students. The team is led by a graduate student who typically is familiar with the customer. Other members are newer graduate students learning the processes and younger undergraduate students who are learning how the GasDay Project works. Everyone participates, and much of the work is done in pairs to facilitate learning and catching errors.

The senior GasDay team members who lead data and manufacturing activities serve as project managers and subject matter experts. Because of the rapid turnover of GasDay members due to co-op employment and graduation, the teams serve to continually train newer members for more complex roles. Pairing undergraduate and graduate students allows undergraduate students to become aware of opportunities for graduate study.

IT Support and Business Operations

Two additional activities providing interesting work experiences are (1) supporting the significant computing environment of the GasDay Project and (2) participating in the business operations of the project.

Marquette University provides IT support and basic management of computer systems; however, the GasDay Project computer environment is customized enough that the project requires at least one student, and often two, to maintain all equipment and software. A common task is to equip a new or refurbished computer system with a standard GasDay software configuration so that any student on any team can log onto that computer and find all the tools they need. Interspersed with this are typical occasional failures of power supplies, hard drives, and other components. Students on the GasDay IT support team are able to replace failed parts, secure rebuilt systems, restore missing data, and reconnect to GasDay network resources.

GasDay also tries to maintain at least one student on staff to assist with the business of GasDay. Typical tasks for this role include generating license renewal notices, assisting in proposal development, developing marketing materials, and project management. This role is often filled by a student from Marquette's College of Business Administration.

New Student Development

There is a tremendous learning curve when joining GasDay. A new team member must absorb a significant amount of information about natural gas as a fuel, energy industry concepts, GasDay's role in that industry, and countless details about the data, methods, and results that are central to the product's function. Students also participate in GasDay's relationships with its customers, and must work hard to become familiar with the various customized GasDay configurations.

The typical entry point for a new team member is to join the data and manufacturing team. Almost immediately, a new team member is able to apply basic MATLAB skills to work processing customer data or providing assistance in one of the many ongoing research activities. Students who have the best experience at GasDay are the ones willing to dig into an assignment and get comfortable working under the direction of a graduate student or faculty member. The GasDay Project has several weekly structured meetings that new team members are expected to attend. This participation helps accelerate members' contributions to the project.

Early in the project's history it would take at least a semester, and sometimes two, for a new team member to find a way to contribute and become productive. Over the years it has become obvious that the best mentors to new team members are existing graduate students, who take the lead in organizing and overseeing most student orientation activities. Now a new student joining the project at the start of the fall semester becomes a key contributor to some of the GasDay configurations tested, built, and delivered later that same semester.

GasDay Project Challenges

GasDay's "academic" staff is comprised of its students and two faculty members. Administrative staff includes a business manager, a software team leader, and an administrative assistant. The majority of project workers are students who graduate and pursue careers outside Marquette. This complicates ongoing operations in a business developing a complex, customized product.

A typical student will start working for the GasDay Project when they enter either as a freshman undergraduate or new graduate student. Undergraduate students have less background and experience to bring to the project, but are often able to spend four years working on the team. Graduate students usually will have a richer background, but most are master's degree students who participate for only two years. Everyone starts out at about the same level of ability, with some classroom knowledge, but little work experience. This represents GasDay's two significant staffing challenges: inexperience and frequent turnover.

Conclusion

This paper has described Marquette University's GasDay Project, a working software product business that provides undergraduate and graduate students the opportunity to apply their classroom learning in a real, functioning business environment. It is predicated on student-centered learning methods, which are the cornerstone of modern engineering education practice. Some benefits to students are:

- Hands-on learning in a business setting with real-world consequences for successes and failures.
- Direct contact with customers and other industrial partners, and opportunities to teach them how to use GasDay and learn from them and their experiences with the product.
- Experience with project management and the importance of working in a setting with competing priorities that must be met with a fixed set of resources.
- Knowledge of how research is conducted, and the process to take it from the laboratory to the marketplace.
- Immediately relevant career skills.
- Financial support in the form of hourly salaries or research assistantships.

Students leave the project with genuine work experience, letters of reference, and the experience of having participated in the larger setting of the College of Engineering beyond the classroom.

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