Advances in Engineering Education

FALL 2021

Iron Range Engineering

RON ULSETH
Iron Range Engineering
Virginia, Minnesota

BART JOHNSON
Itasca Community College
Grand Rapids, Minnesota

AND

CHRISTINE KENNEDY
Iron Range Engineering
Virginia, Minnesota

ABSTRACT

In this paper, we address the achievements to date and the learnings from the development and ten-year implementation of the Iron Range Engineering (IRE) program while articulating its future directions. IRE uses research-based instructional strategies to implement a project-based learning (PBL) curriculum where authentic design sits at the heart of each semester's learning experiences. Industry projects are used to provide the learning context that spans the three engineering domains of professional, technical, and design capabilities. Delivered as an upper-division program to graduates of community colleges, the IRE model attracts a wider gender, racial, and socio-economic diversity. The rural IRE program has been replicated successfully in a metro region. Both programs have small enrollments, are resource intensive, and immerse student engineers in two years of PBL curriculum with industry clients leading to a Bachelor of Science in Engineering (BSE). Many unique learning strategies with the potential to advance engineering education have been developed by these programs. In an effort to propagate the use of these strategies, IRE has developed a new program designed for higher enrollments while both decreasing resource intensity and further expanding the diversity of the profession. This new entity, known as the Iron Range Engineering Bell program, attracts community college graduates from across the U.S.

Using the framework of looking forward, this paper briefly describes the motivations behind the IRE model, its background, and the specific details of its philosophies and implementation. In the results section, both advancements and new learning strategies are described in a way that others can seek inspiration for possible adaptation. Finally, the new Bell program is described along with its potential for impact on change in engineering education.

Key words: Professional Practice, Educational Setting, Diversity

INTRODUCTION

The motivations to start the Iron Range Engineering (IRE) program came from regional economics and dissatisfaction by the founders with the status quo in engineering education (Ulseth, 2016). IRE emerged from a successful community college engineering program and became a collaboration between that college, Itasca Community College, and Minnesota State University, Mankato with Mesabi Range College as the host location. The curricular model was adapted from the Aalborg University (Denmark) model of project based learning (PBL) where semester projects from industry sit at the center of the curriculum. This contrasts with traditional engineering curricula that have technical and professional learning that is separate from the student design and professional practice experience. Students who complete the program earn a Bachelor of Science in Engineering from Minnesota State University, Mankato. Student engineers can choose a focus area and graduates have focused in mechanical, electrical, biomedical, chemical, civil, aeronautical, process, software, computer, or environmental engineering.

One of the specific aims of the startup program was to better align instructional practices with ABET outcomes (Bates, Allendoerfer, Ulseth, & Johnson, 2016 and Johnson, 2016) as compared to the founders' perceptions of how traditional programs were aligned at the time. Validation of the alignment was received with the awarding of the 2017 ABET Innovation Award (https://vimeo.com/239716994). The model was replicated as Twin Cities Engineering (TCE), which is hosted by another community college in Minnesota, in 2012.

One of the specific learnings of the IRE model is that, as developed, it was geographically bound in its scalability. Broadening its adaptability in the next round of continuous improvement needed to be explored. These learnings became the motivations behind the desire for *IRE Version 2.0*, a "future direction" for engineering education. This new model, now called the IRE Bell program, started its first cohort in August 2019. The many innovative strategies developed in the first 10 years of IRE have been translated to Bell, where community college graduates from around the U.S. spend one semester in the "Bell Academy" before spending the last two years of their education on co-op placements in industry while completing their academic requirements online. The Bell model was inspired by the Charles Sturt University engineering program in Australia (Lindsay & Morgan, 2016 & Rogalsky, Johnson, & Ulseth, 2020).

BACKGROUND

Prior to and during the development of IRE, there were several calls for improving engineering education to meet the societal needs of today and the future (National Academy of Engineering, 2004; American Society for Engineering Education, 2015; Martin, Maytham, Case, & Fraser, 2005; Almi, Rahman,

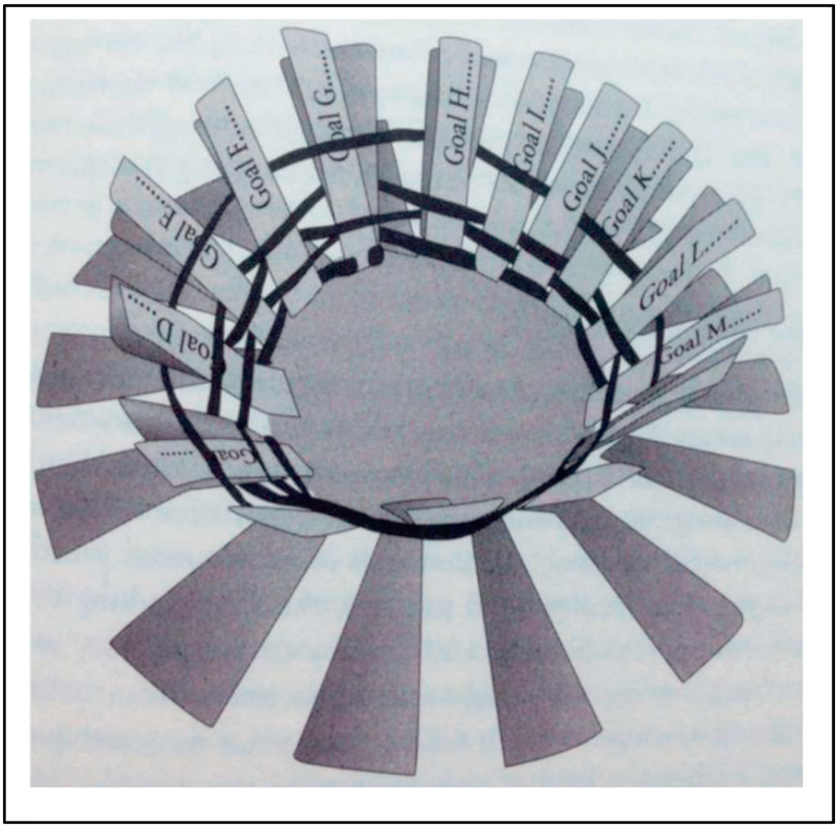

Figure 1. Sheppard networked component model (used with permission).

& Purusothaman, 2011; Hasse, Chen, Sheppard, Kolmos, and Mejlgaard, 2013). In response, specific emphasis was placed on the development of the whole engineer, in addition to the traditional focus on *technical*, increased emphasis was placed on the *design* and *professional attributes* of engineering graduates (Sheppard, Macatangay, Colby, & Sullivan, 2009). Figure 1 is a graphic description of Sheppard's model wherein a circle-spiral of learning of engineering principles from the professional, design, and technical domains are introduced on the first revolution and then used again at higher and higher levels of sophistication in subsequent revolutions that are situated in activities that closely simulate professional practice. This helical learning model of repeated exposure to engineering principles at increasing levels of sophistication is, along with PBL, at the center of the program's curricular approach.

The development of the program began in the fall of 2009 with a pioneering group of 14 students. That fall students, faculty, and staff formed a development team with courses starting in the spring of 2010. ABET accreditation was achieved in 2013 (renewed in 2017), and ABET's Innovation Award was received in 2017 for the effort on continuous improvement and the curricular balance reflecting their criteria. Each semester faculty, staff, and student engineers evaluate the curriculum and continue to improve the curriculum in a continuous development approach. The focus of the program development was and still is framed with this paper's keywords: Professional Practice, Diversity, and Educational Setting.

Professional Practice

Professional practice is at the heart of the IRE project-based learning model where students work on teams to complete a project each semester. Adapted from the Aalborg University PBL model (Kolmos & Fink, 2004), the design projects are the hub upon which design learning, technical learning, and professional learning take place. A key difference between IRE and Aalborg is where Aalborg's technical learning is driven by an established curriculum, IRE's is driven by emerging needs of the project, an advantage of IRE's smaller scale allowing for this level of flexibility. The projects are used to create the professional practice learning environment, bridging the gap between engineering education and professional practice. Integral to the design is the acquisition of technical knowledge that is required to complete the design and is grounded in the industry context.

Diversity

Especially in the United States, women, Hispanics, Black/African-Americans, and other minorities continue to be underrepresented in the engineering profession as compared to their representation in society (NSF, 2017). Community college demographics, unlike traditional universities enrolling engineering students, are more aligned with societal representation in the United States (American Association of Community Colleges, 2018). The IRE program was purposefully designed to enroll community college graduates in the upper-division (last half of bachelors) program. Thus, the goal is to have a more diverse student body and graduates entering the profession (Johnson, Ulseth, Wang, 2018).

Educational Setting

The learning environment of IRE was designed (Johnson & Ulseth, 2017) to specifically address the systemic problem that most educational experiences were based on an assumption that the development of professional competencies can occur in a set of discrete finite episodes with a beginning and end (Wenger, 1998). This was despite the fact that both students and employers expected a higher degree of synergy between what is learned in classroom and what is needed in the field (Passow, 2012). Learning through industry projects was intended to bridge this gap.

THE IRE MODEL

The model can best be described through the projects that are at the center of the PBL model and how the design, professional, and technical competencies are acquired. Figure 2 presents the IRE curricular model.

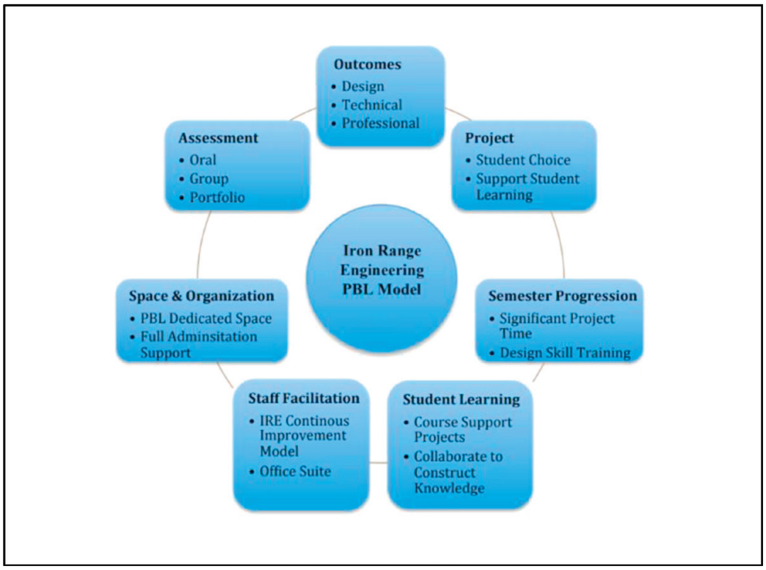

Figure 2. Iron Range Engineering PBL Curricular Model (Johnson, 2016).

Design Projects Each Semester

Students provide input into desired types of projects in advance of the semester. Staff then seek relevant projects from industry, create teams, and connect students with projects based on student preference and technical development needs. An academic faculty member or adjunct Professional Engineer (P.E.) is assigned as the project facilitator and guides student engineers through design process learning. See Figure 3.

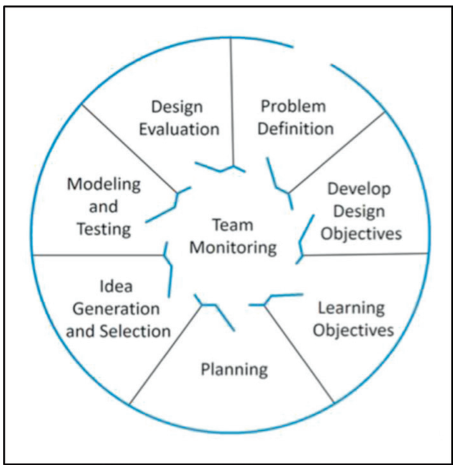

Figure 3. Iron Range Engineering Design Process (Ulseth and Johnson, 2015b).

Throughout the semester, faculty members serve on design review panels where student engineers defend their progress on their project, describe their learning experience, and discuss past accomplishments and future plans. An important point to make about the projects is that they are authentic, rather than being contrived. This reality leads to messy obstacles and changes of scope emerging throughout the semester. This reality also means students and clients highly value the project outcomes.

As the semester progresses, students create written (reports), verbal (presentations), and visual (posters, prototypes, and/or products) documentation of their work. They often must verbalize the dynamic status of their project to peers, clients, and external visitors. This verbalization leads to an identity building that is associated with the particular team and its success (Ulseth, 2016). Project teams are vertically integrated with graduating seniors on the same team as entering juniors.

Design, Professional, and Technical Competencies

The program is outcome-based; students are explicitly made aware of the outcomes at the beginning of the program and then track their progress against desired performance indicators towards graduation (Ulseth & Johnson, 2014). Learning activities include:

- Using an engineering design approach to complete the semester project,
- Active learning conversations with faculty,
- Professional development workshops from external experts,
- Frequent reflection to develop metacognitive skills leading to a proficiency in being reflective practitioners and self-directed learners.

Technical learning takes place in one-credit modules with students completing 8 modules per semester. Core credits (16) come from what would be traditionally called mechanical and electrical engineering. The elective credits (16) are where the student can define the engineer they want to be by deeply diving into a specific area or get broader exposure to a wider variety of areas. Students are guided through this selection process by a faculty advisor through the development of an overall learning plan and continual plan monitoring. Much emphasis is put on choosing competencies that closely align with the current project, providing students with a stronger context for the technical learning leading to higher levels of motivation. Student engineers can choose a focus area by selecting 14 of the 16 electives in an engineering discipline and at least two of four projects related to that discipline. The majority choose electrical and mechanical engineering, with the remainder choosing areas like computer, civil and biomedical or choosing not to focus but earn a degree across a breadth of topics that might support a career in an area like renewable energy or technical entrepreneurship.

Professional learning is approached as a single continuum of continuous improvement from day one to graduation, as compared to the four discrete cycles of the design process and the technical learning experiences. Students develop a professional development plan (PDP) with a chapter for each of the professional areas of competency: leadership; verbal communication; written communication; teamwork; ethical responsibility; professional responsibility; learning about learning; ability to work in a diverse environment; and knowledge of contemporary issues.

An additional essential element is the development of self-directed learning skills students will need upon graduation to independently acquire the technical competence they will need as practicing engineers. Faculty members provide appropriate levels of scaffolding for students each semester with decreasing levels of prescriptiveness in the learning activities as the students progress through the four semesters.

Student Stories

Essential to understanding the model are the student stories. Below are just a few examples of how different project experiences lead to the varying careers of graduates:

- Damaris Onchaba ('17), a project manager at *rms Surgical*, grew up in Kenya and moved to Minnesota where she participated in projects on cardiovascular engineering that combined research and entrepreneurship for a start-up company.
- Noah Block ('15), Particle Scientist at TSI Incorporated, built on his projects with additive manufacturing and fused deposition modeling parts and undergraduate research experiences to complete his PhD in the characterization of engine nanoparticle emissions at the University of Minnesota, Fall 2020.
- Andrew Hanegmon ('15), owner-director of a community maker space, focused on entrepreneurial projects defined and championed by students, including one he led evaluating the need for a local maker space and technology incubator in northern Minnesota, developing a business plan, and then winning a competitive economic development grant for seed money that supported the creation of the maker space.
- Christine Kennedy ('11), a member of the first cohort and current program director, spent several years in industry before building off her pioneering curriculum development experience to return and lead the program.

RESULTS THAT LOOK TO THE FUTURE

The results from the implementation of the first ten years of the IRE model that are forward-looking and are also of value to the greater engineering education audience are the curricular advances and learning strategy development. Effectiveness of the model has been measured and published in two PhD dissertations and through 3 NSF Grants. In particular, effectiveness was established in metacognitive skill development by Hacker, Plumb, & Marra (2017, 2018, 2019), in self-directed learning development by Ulseth and Johnson (2015a) and Ulseth (2016) and in professional skill development by Johnson and Ulseth (2015) and Johnson (2016).

Curricular Advances

Advances have been made in professional practice, educational setting, and instruction for diversity.

Professional Practice

Barnett and Coate (2004) presented a continuum of knowing-acting-being that has been interpreted to classify engineering programs as being more theoretical (thinking prized over doing), professional (where a wider spectrum of skills and abilities are valued), or humanistic (solutions aimed specifically at society and the environment) (Jamison, Kolmos, and Holgaard, 2014). The founders of IRE perceived that traditional engineering programs were more theoretical whereas industry was wanting to value the broader set of skills as classified in the professional programs (Johnson, 2016). IRE was developed specifically to be a professional practice program (Ulseth, 2016). To this end, the upper-division curriculum is 20% design, 27% professionalism, and 53% technical. In comparison, traditional engineering programs in the same region are 10% design, 5-10% professional, and 75-80% technical. This re-balancing of curriculum showing value towards the broader set of skills needed in professional practice is one of the advances made available by the implementation of the IRE model.

Educational Setting

The learning environment was designed to enhance the identity building of the students as emerging engineers. One aspect of the environment is the "team room" adopted from Aalborg University where there are over 1000 group rooms dedicated to student teams. The space provides team growth, motivation, and the development of positive work attitudes (Spliid and Qvist, 2007). Another attribute of the learning setting is professional culture. Students adhere to a dress code. Language appropriate to the profession is modeled by staff and developed in students. Particular attention is paid to timeliness. The learning space is operated much like a consulting firm where student engineers work 40- to 50-hour work weeks. Further, the work being done by student engineers is the solution of industry problems for industry clients.

Instruction for Diversity

It is widely understood that active and collaborative learning strategies improve persistence, attitudes, and achievement in engineering (AAAS, 2019). In particular, these pedagogies are more likely to benefit underrepresented groups such as women, racial/ethnic groups, and socio-economically disadvantaged students (Kuh, 2008; Lorenzo, Crouch & Mazur, 2006). The IRE PBL model is highly active and collaborative as will be described in the following section. Further, the target audience for the IRE model includes community college graduates that are from a greater cross-section of these groups (AACC, 2018).

Learning Strategies

There are a wide variety of learning strategies that have been developed through the 10-year evolution of the IRE model. The strategies are in the technical, professional, and design domains (Ulseth, 2016). Example strategies are described below.

Technical Strategies

There are three primary tenets to the IRE approach to technical learning. The first is an explicit longitudinal expectation of learned knowledge. Engineering principles are identified as they are accumulated and then students are held accountable for the principles through semesterly exams. Once a principle is learned, it is tested until graduation. Second, a balance is maintained between conceptual knowledge and analytical knowledge. Students have verbal exams discussing conceptual understanding and use of application/theory and are then further evaluated on their calculational abilities through the technical work they complete for their clients. Third, reflection is scaffolded and executed throughout the technical curriculum. These reflective activities build metacognitive skill and practice leading to student development as self-directed learners (Ulseth, 2016).

Professional Strategies

The growth of the emerging engineer is embraced as a continuous improvement process through the lens of SMART methodologies (specific, measurable, attainable, relevant, and time-based). Students write professional development goals each semester along with action plans to achieve the goals. Progress is monitored throughout the semester and evaluated at the end. Weekly seminars are held to provide students with best-practice strategies for growth. Students become expert communicators giving four to five TED-type talks, writing over 50 technical papers, practicing job-search skills, and writing three entries each week in a learning journal. An external technical communication professional provides developmental feedback one-on-one for each student each semester.

Design Strategies

The IRE model of engineering design learning has several parallels with capstone senior design at many engineering universities. One significant difference is that design happens in each of the four semesters of upper-division as compared to only the final two semesters. Each engineering design team is mentored by a staff engineer who has engineering industry practice. The projects are highlighted at the center of student learning. Student engineers present their scoping, ideation, and final designs to their peers and their clients. Technical design reviews happen before faculty panels three times per semester. Final design documents and other relevant deliverables are created and delivered to the clients.

POTENTIAL TO CHANGE

As stated in the results section, the Iron Range Engineering Model has demonstrated advancements and strategies for consideration in engineering education. The logical next step in the progression is to further develop the model to operate beyond the two regional-based models. The work has begun with the Iron Range Engineering "Bell Program." The inspiration for the Bell Program model is from the current Iron Range Engineering Model and the Charles Sturt University (Lindsay & Morgan, 2016) model in Australia. The Charles Sturt University (CSU) model uses extensive cooperative education apprenticeships and on-line technical learning (Morgan & Lindsay, 2015). The Bell Program draws its structure from CSU and its learning strategies from IRE.

Video Link: https://www.youtube.com/watch?time_continue=4&v=z3NGZoi-9o0

The Bell program delivers an upper-division engineering education that is centered on student experiences working directly in industry through co-op employment (Johnson & Ulseth, 2018). Students spend one semester on campus acquiring design, professional, and self-directed learning competence before spending 24 months on co-op apprenticeships. See Figure 4 for a graphical timeline of the Bell program.

The co-op model will position students to work directly in industry, completing projects for the last two years of their education while being supported in their technical and professional development by professors, facilitators, and their own peers using digital communication. It continues the IRE model focus on learning experiences being more embedded in professional practice, in contrast to the more traditional model of engineering where learning about the profession is done in the abstract in a classroom. It shifts the IRE model from "bringing industry to the classroom" to "bringing the classroom to industry". Not only does this further bridge the gap between the classroom

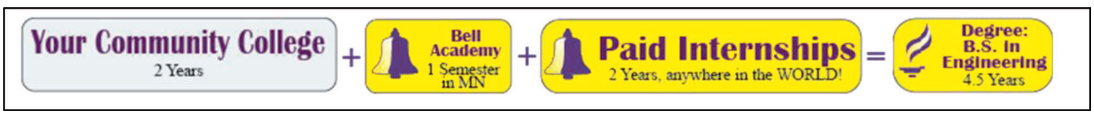

Figure 4. Student timeline in Bell program.

and professional practice, the learning experience, as designed, opens doors for greater access to engineering education. Aimed at community college graduates, it serves a more ethnically and gender-diverse student body (currently 35% non-white; 22% women). The Bell Program is an additional pathway to the BSE degree under the Iron Range Engineering umbrella.

The specific goals for the new model include: 1) the creation of more effective engineering graduates; 2) a model for diversification of the engineering profession as entering students come from more diverse community colleges; 3) adaptation of effective learning strategies created in the IRE model; 4) very low net cost to the student as the costs of tuition are offset by 24 months of co-op employment.

Looking to the future, the IRE model has provided a glimpse into how engineering education can be done differently with more focus on preparation for professional practice, continuous development of the individual across the three domains of the profession, and extensive use of research-based instructional strategies. Implementation of the strategies into an apprenticeship-type model such as the Bell program opens new doors to accessibility to the profession for a greater cross-section of underrepresented gender, racial, and socio-economic groups.

REFERENCES

Almi, Nurul, Ezza Asyikin Mohamed, Najwa Abdul Rahman, Durkadavi Purusothaman, and Shahida Sulaiman. 2011. "Software engineering education: The gap between industry's requirements and graduates' readiness." In *2011 IEEE Symposium on Computers & Informatics*, pp. 542–547. IEEE, 2011.

American Association for the Advancement of Science (AAAS). 2019. "Levers for Change: An assessment of progress on changing STEM instruction." Accessed July 30, 2019. https://www.aaas.org/resources/levers-change-assessment-progress-changing-stem-instruction

American Association of Community Colleges (AACC). 2018. "Community College Fast Facts." Accessed May 28, 2018. https://www.aacc.nche.edu/research-trends/fast-facts.

American Society for Engineering Education (ASEE) 2015. "The Attributes of a Global Engineer Project, Global Engineering Deans Council (GEDC)." Accessed 20 July, 2017. http://www.gedcouncil.org/publications/attributes-global-engineer-project.

Barnett, Ronald, and Kelly Coate. 2004. *Engaging the curriculum*. McGraw-Hill Education (UK).

Bates, Rebecca A., & Allendoerfer, Cheryl, & Ulseth, Ron R., and Johnson, Bart. 2016. "On the Use of Outcomes to Connect Students to an Engineering Identity, Culture, and Community." In *Proceedings of the 2016 ASEE Annual Conference & Exposition*, New Orleans, Louisiana.

Haase, Saane, Helen L. Chen, Sheri Sheppard, Anette Kolmos, and Niels Mejlgaard. 2013. "What does it take to become a good engineer? Identifying cross-national engineering student profiles according to perceived importance of skills." *International Journal of Engineering Education* 29, no. 3 (2013): 698–713.

Hacker, Douglas J., Carolyn Plumb, Rose M. Marra, and Shann Bossaller. 2019. "How Problem Solving Skills Develop: Studying Metacognition in a PBL Engineering Curriculum." In *Proceedings of the 2019 126th Annual meeting of American Society for Engineering Education*. Tampa, Florida, June 16–19, 2019.

Jamison, Andrew, Anette Kolmos, and Jette Egelund Holgaard. 2014. "Hybrid learning: An integrative approach to engineering education." *Journal of Engineering Education* 103, no. 2 (2014): 253–273.

Johnson, Bart, and Ronald Ulseth. 2015. "Professional Competency Development in a PBL Curriculum." In *Proceedings for 5th International Research Symposium on PBL, part of International Joint Conference focus on the Learner in Engineering Education (IJCLEE), Mondragon University, Mondragon, Spain. July 6–10, 2015. 116-126*. https://vbn.aau.dk/ws/portalfiles/portal/217363939/Global_research_community_collaboration_and_development_final.pdf

Johnson, Bart. 2016. *Study of Professional Competency Development in a Project-Based Learning (PBL) Curriculum*. PhD dissertation. Aalborg University, 2016. DOI: 10.5278/vbn.phd.engsci.00092

Johnson, Bart, and R. Ulseth. 2017 "Student experience for the development of professional competencies in a project-based learning curriculum." *The International Journal of Engineering Education* 33, no. 3 (2017): 1031–1047.

Johnson, Bart, Ron Ulseth and Yuezhou Wang. 2018 "Applying Design Based Research to New Work-Integrated PBL Model". In *Proceedings of the 7th International Research Symposium on PBL: Innovation, PBL and Competences in Engineering Education, Beijing, China, 2018*, 11–22. Alborg: Aalborg University Press. https://vbn.aau.dk/ws/portalfiles/portal/289259682/2018_IRSPBL_Proceedings_Innovation_PBL_and_Competence.pdf

Johnson, Bart, and Ron Ulseth. 2018. "Developing the Next Generation of Co-operative Engineering Education". In *Proceedings of the PAEE/ALE'2018, 10th International Symposium on Project Approaches in Engineering Education (PAEE) and 15th Active Learning in Engineering Education Workshop (ALE), University of Brasília, Brasília, Brazil, 2018*, 400–407. Guimarães, Portugal: Department of Production and Systems – PAEE association School of Engineering of University of Minho. http://paeeale.unb.br/_upload/PAEE_ALE_2018_proceedings.pdf

Kolmos, Anette, and Flemming K. Fink. 2004. *The Aalborg PBL model: progress, diversity and challenges*. Edited by Lone Krogh. Aalborg: Aalborg University Press.

Kuh, George D. 2008. "Excerpt from high-impact educational practices: What they are, who has access to them, and why they matter." *Association of American Colleges and Universities* (2008): 19–34.

Lindsay, Euan, and James Morgan. 2016. "The Charles Sturt University Model: Reflections on Fast-track Implementation." In *2016 ASEE Annual Conference and Exposition*.

Lorenzo, Mercedes, Catherine H. Crouch, and Eric Mazur. 2006. "Reducing the gender gap in the physics classroom." *American Journal of Physics* 74, no. 2 (2006): 118–122.

Marra, Rose M., So Mi Kim, Carolyn Plumb, D. Hacker, and S. Bossaller. 2017 "Beyond the Technical: Developing Lifelong Learning and Metacognition for the Engineering Workplace." In *Proceedings of the 2017 124th Annual meeting of American Society for Engineering Education*. Columbus, Ohio, June 25–28, 2017.

Marra, Rose M., Carolyn Plumb, and Douglas J. Hacker. 2018. "Developing Metacognitive Skills in PBL Undergraduate Engineering" In *Proceedings of the 2018 125th Annual meeting of American Society for Engineering Education*. Salt Lake City, Utah, June 24–27, 2018.

Martin, Rosanna, Bryan Maytham, Jennifer Case, and Duncan Fraser. 2005. "Engineering graduates' perceptions of how well they were prepared for work in industry." *European Journal of Engineering Education* 30, no. 2 (2005): 167–180.

Morgan, James, and Euan Lindsay. "The CSU Engineering Model." In *26th Australian Association for Environmental Education (AAEE) Conference*. Geelong, Australia, Australia, December 6–9, 2015.

National Academy of Engineering, U. S. (NAE). 2004. *The engineer of 2020: Visions of engineering in the new century*. Washington, DC: National Academies Press, 2004.

National Science Foundation (NSF). 2017. "Who earns S&E associate's degrees in the United States?" Accessed October 17, 2017. https://www.nsf.gov/nsb/sei/edTool/data/college-13.html.

Passow, Honor J. 2010. "Which ABET competencies do engineering graduates find most important in their work?" *Journal of Engineering Education* 101, no. 1 (2012): 95–118.

Rogalsky, D., Johnson, B., & Ulseth, R. (2020). "Design-Based Research: Students Seeking Co-op in New Educational Model." In *Proceedings of the 2020 American Society of Engineering Education Annual Conference and Expo*.

Sheppard, Sheri D., Kelly Macatangay, Anne Colby, and William M. Sullivan. 2009. *Educating engineers: Designing for the future of the field*. San Francisco, CA: Jossey-Bass.

Spliid, Claus Christian Monrad, and Palle Qvist. 2007. "Environment, belonging and social world in the Aalborg Model: preliminary theoretical explanation." In *Proceedings of the 13th Annual Dun Konference on University Education*. Aalborg University, Aalborg, Denmark, May 31 – June 1, 2007.

Ulseth, Ron, and Bart Johnson. 2014. "100% PBL Program: Startup Phase Complete." In *Proceedings of the 2014 44th Annual Frontiers in Education (FIE) Annual Conference*. Madrid, October 22–25, 2014.

Ulseth, Ronald, and Bart Johnson. 2015a. "Self-Directed Learning Development in PBL." In *Proceedings for 5th International Research Symposium on PBL, part of International Joint Conference focus on the Learner in Engineering Education (IJCLEE)*, Mondragon University, Mondragon, Spain. July 6–10, 2015. 55–63. https://vbn.aau.dk/ws/portalfiles/portal/219796997/PAEE2015_proceedings_vf_AAU_press.pdf

Ulseth, Ronald, and Bart Johnson. 2015b. "Iron Range Engineering PBL Experience." In *Proceedings for International Symposium on Project Approaches in Engineering Education (PAEE), part of International Joint Conference focus on the Learner in Engineering Education (IJCLEE)*, Mondragon University, Mondragon, Spain. July 6–10, 2015. 48–57. https://vbn.aau.dk/ws/portalfiles/portal/217363939/Global_research_community_collaboration_and_development_final.pdf

Ulseth, Ronald. 2016. *Self-directed learning in PBL*. PhD dissertation, Aalborg University. DOI: 10.5278/vbn.phd.engsci.00091

Ulseth, Ronald, and Bart Johnson. 2017. "Self-directed learning development in PBL engineering students." *The International Journal of Engineering Education* 33, no. 3 (2017): 1018–1030.

Wenger, Etienne. 1998. "Communities of practice: Learning as a social system." *Systems thinker* 9, no. 5 (1998): 2–3.

AUTHORS

Ron Ulseth is the director of the Iron Range Engineering Bell program and a founder of Iron Range Engineering. His other appointments include as External Associate Professor at the Aalborg University UNESCO Center for Problem Based Learning in Denmark and as an unlimited full-time instructor in the Itasca Community College (Minnesota) engineering program. He has been in the classroom, teaching more than 20 credits per year for more than 30 years. Ron is a social entrepreneur who has been at the leading edge of engineering educational change. His B.S. degree is in civil engineering from the University of North Dakota, while his M.S. is in mechanical engineering from the University of Central Florida. He earned his Ph.D. in engineering education from Aalborg University. A retired Commander as an Engineering Officer in the US Navy reserve; he is also licensed as a professional engineer in the state of Minnesota.

Bart Johnson is the provost and senior academic officer of Itasca Community College. He is a co-founder and development advisor for the Bell and Iron Range Engineering, which was the ABET 2017 Innovation Award winner and identified in a recent MIT report on the top 5 emerging world engineering education leaders. His nine years of classroom experience include introduction to engineering, solid modeling, professional and design development, and engineering mechanics courses. Bart is active in engineering education research, especially in PBL and professional competency development. His B.S. degree is in mechanical engineering from the North Dakota State University, while his M.S. is in mechanical engineering from the University of Michigan. He earned his Ph.D. in engineering education from Aalborg University. Prior to Itasca, he was a design engineer in John Deere's Construction and Forestry Division.

Christine Kennedy is the Director of Iron Range Engineering and was one of the first generation of graduates who pioneered and graduated from the IRE program. She earned her A.S. in Engineering from Itasca Community College before attending IRE where she received her B.S. in Engineering. She then worked 5 years in heavy industry where she managed multi-million dollar projects as well as designed structures and mechanical systems, and supervised an operations crew. Christine graduated with her M. S. in Engineering Management in May 2018, with her thesis being in the realm of Industrial Psychology. As the director, Christine manages IRE's budget, coordinates recruiting and other events around campus, facilitates student project teams, teaches advanced project management techniques, ensures IRE maintains its ABET Accreditation, and works on continuous improvement efforts.