Proceedings of the 2021 IISE Annual Conference
A. Ghate, K. Krishnaiyer, K. Paynabar, eds.

Industrial and Systems Engineering Education and Entrepreneurial Mindset: A Systematic Literature Review

Nadiye O. Erdil
Department of Mechanical and Industrial Engineering
University of New Haven
West Haven, CT, USA

Abstract

Entrepreneurial Mindset (EM) is gaining attraction in engineering education. Efforts in fostering EM in students range from program wide to individual instructor-led approaches. EM, which embraces entrepreneurs and intrapreneurs, is more than what entrepreneurship represents. Entrepreneurship refers to activities associated with the intent to start a new business or venture, while intrapreneurship is about knowledge and skills used for initiatives within companies or corporations. Whether they become intrapreneurs or entrepreneurs, EM empowers engineers to develop sound technical solutions that address customer needs, are feasible from a business perspective, and have societal benefits. The skills targeted include, but not limited to, opportunity identification, market evaluation, customer engagement, solution assessment and communication in economic terms and customer value, business model creation, and so on. Industrial and systems engineers (ISE) are trained in system and process design, problem solving, and process improvement; they use mathematical, scientific and technical knowledge in modeling, analyzing, and solving problems involving people, information, equipment, material and financial assets. Therefore, there is a natural synergy and overlap between EM and ISE. In this paper, first the alignment of EM with the ISE Body of Knowledge is discussed. Then the results of a systematic literature review conducted to evaluate to what extent EM is explicitly integrated into ISE education are presented. The findings help reveal the current deployment level of EM in ISE education, and serve as a resource for ISE educators and researchers by providing examples of EM implementation with ISE focus.

Keywords
Entrepreneurial Mindset, ISE education, intrapreneur, entrepreneur, ISEBoK.

1. Introduction
Entrepreneurship refers to activities associated with the intent to start a new business or venture. While this domain had been closely associated with business schools and business education in the past [1], the focus on entrepreneurship in other disciplines, including engineering, has been on the rise [2]-[3]. Entrepreneurship in engineering education, however, encompasses more than what entrepreneurship in the traditional sense represents. It aims to develop knowledge and traits needed for opportunity recognition and value creation in any context [4]. For entrepreneurs this is in new business ventures and for intrapraneurs this is in their organizations as employees. In either setting, a particular set of skills and attitudes are needed, which combined defines entrepreneurial mindset (EM).

Efforts in fostering EM in engineering students, although still relatively young, range from program wide to individual instructor-led approaches [5]-[9] and center around empowering engineers to develop sound technical solutions that address customer needs, are feasible from a business perspective, and have societal benefits. This empowerment is achieved by equipping students with skills and attitudes that will help them become better at identifying opportunities to create value. Opportunity identification and value creation are also at the center of industrial and systems engineering (ISE) practice whether this is in system/process design or improvement.

Therefore, there is a natural synergy and overlap between EM and ISE. In this paper, first the alignment of EM with the ISE Body of Knowledge is discussed. Then the results of a systematic literature review conducted to evaluate to what extent EM is explicitly integrated into ISE education are presented. The findings help reveal the current deployment level of EM in ISE education, and serve as a resource for ISE educators and researchers by providing examples of EM implementation with ISE focus.

2. Entrepreneurial Mindset in ISE

To identify the synergy and overlap between EM and ISE, first EM must be defined. EM, as mentioned above, is a particular set of skills and attitudes that are needed for opportunity identification and value creation. The EM framework used in this study, and in the most recent examples found in the literature, is the one proposed by the Kern Entrepreneurial Engineering Network (KEEN) [10]. This framework defines *curiosity*, *connections* and *creating value* (3Cs) as the attitudes of entrepreneurial mindset. The *3Cs* are coupled with *opportunity* and *impact* as the skills that help magnify the value created (see **Table 1**).

Table 1 Entrepreneurial Mindset Framework

<table>
<tr><th>Behaviors</th><th>Skills</th></tr>
<tr><td>CURIOSITY
Demonstrate constant curiosity about our changing world;
Explore a contrarian view of accepted solutions.</td><td rowspan="2">OPPORTUNITY
• Identify an opportunity
• Investigate the market
• Create a preliminary business model
• Evaluate technical feasibility, customer value, societal benefits, economic viability
• Test concepts quickly via customer engagement
• Assess policy and regulatory issues</td></tr>
<tr><td rowspan="2">CONNECTIONS
Integrate information from many sources to gain insight;
Assess and manage risk.</td></tr>
<tr><td rowspan="2">CREATING VALUE
Identify unexpected opportunities to create extraordinary value;
Persist through and learn from failure.</td><td>IMPACT
• Communicate an engineering solution in economic terms
• Communicate an engineering solution in terms of societal benefits
• Validate market interest
• Develop partnerships and build a team
• Identify supply chains distribution methods
• Protect intellectual property</td></tr>
</table>

The attitudes associated with EM under the *3Cs* are qualities that an ISE graduate is expected to possess. After all, without questioning the status quo (curiosity), portraying the big picture (connections) and keeping eye on the ultimate goal (value), an ISE will not be able to perform the essential functions of the job, which is defined as "*design, improvement, and installation of integrated systems of people, materials, information, equipment and energy*" [11]. Most of the skills listed under *Opportunity and Impact* are already part of ISE curriculum explicitly. Identifying opportunities, evaluating and communicating technical feasibility, customer value, and economic viability, identifying and engaging customers, assessing policy and regularity issues, working in teams and addressing supply chain management are topics spread out over the ISE curriculum in several core courses. The alignment of EM and ISE is evident in the Industrial and Systems Engineering Body of Knowledge (ISEBoK) as the outcomes listed above can easily be linked to any of the twelve knowledge areas specified in the ISEBoK: Work Design and Measurement; Operations Research and Analysis; Engineering Economic Analysis; Facilities Engineering and Energy Management; Quality & Reliability Engineering; Ergonomics and Human Factors; Operations Engineering & Management; Supply Chain Management; Engineering Management; Safety; Information Engineering; Design and Manufacturing Engineering, with an additional category of related topics: Product Design & Development; Systems Design & Engineering. For example, financial decision-making is an area that can be found in Engineering Economic Analysis, identifying customer needs in Operations Engineering & Management, and assessing laws and regulations in Safety.

3. Methodology

As discussed above, there is a natural synergy and overlap between EM and ISE. To portray this alignment and to evaluate the extent of EM integration in ISE education, a systematic literature review (SLR) was conducted to identify studies that provide such evidence. SLR is a specialized in-depth literature review in which the researcher attempts to identify, select, evaluate and synthesize evidence to answer a clearly formulated research question. The search typically follows an eight-step process [12, 13]:

1. Problem/Research question formulation
2. Review protocol development and validation
3. Literature search
4. Screening for Inclusion
5. Quality assessment
6. Data extraction
7. Data analysis and synthesis
8. Reporting findings

This study was focused on the questions "how extensive is the integration of EM in ISE education?" and "Are there example implementations to document as references to EM deployment in ISE courses?" The keywords used for the search were '*industrial engineering & entrepreneurship*', '*systems engineering and entrepreneurship*', '*industrial engineering & entrepreneurial mindset*' and '*systems engineering and entrepreneurial mindset*'. To validate the review protocol, a preliminary search was conducted in IISE Conference Proceedings and the steps 3-5 were completed to fine-tune the process. The full SLR was conducted in ABI/INFORM(ProQuest), Academic Search Premier, and Science Direct databases and in two other publication databases which included Advances in Engineering Education and ASEE Conference Proceedings. The rationale behind including the last two databases was that (1) these publications exhibit a high probability of including studies that are relevant to the research questions and (2) these publications were not in the e-databases included in the first search set. The search included only peer-reviewed studies in scholarly journals and conference proceedings and in English. Further subject filters were used in each database to reduce the number of irrelevant hits. The filters were "*entrepreneurs; entrepreneurship; Industrial/Systems engineering; higher education; education*" in ABI/INFORM(ProQuest); "*education; engineering education; entrepreneurship; higher education; industrial/systems engineering; industrial engineers;*" in Academic Search Premier and "*engineering*" in Science Direct. The overall search returned 2,284 articles, which were then narrowed down to 42 by eliminating studies with application scope that did not align with the two research questions stated above. The remaining studies were then analyzed to identify publications with EM integration into an ISE course or curriculum (7 papers) and publications that discuss the role of EM in ISE education (9) resulting in a final set of 16 publications.

4. Results and Discussion

All the studies in the final set were from two sources, IISE and ASEE Conference Proceedings, with one exception, which was captured in the European Research on Management and Business Economics journal. This result supports the view that EM in ISE, and in engineering, is a relatively new area. Because in many fields, including engineering, the broadly accepted scholarly communication model typically follows subsequent incremental forms with conference proceedings appear before the journal articles [14]. Nonetheless, the scholarly conference proceedings are of value to researchers and practitioners as they are tools in developing knowledge base on particular subject areas. The studies with discussions regarding the role of EM in ISE education are shown in Table 2. These handful studies are evidence that EM in ISE education has been a topic of discussion over the past decade, though it is still in infancy. Entrepreneurship was identified as one of the emerging topics for the industrial engineering (IE) curriculum in 2006 [15]. As a response to the changing world of manufacturing, entrepreneurship-driven IE was proposed around the same time [16]. In the following periods, examples of entrepreneurship integration in ISE curriculum sporadically appear in the literature [17]-[25], but no documented evidence of a comprehensive, systematic or regular effort to make EM a part of ISE curriculum at large is observed. Given that the emphasis on EM in engineering is relatively new, this result is not surprising. But then again, when the significant overlaps between EM and ISE are considered, one would expect to see more attention devoted to enhancing ISE curriculum with the explicit integration of EM. One of these studies in Table 2, and several others in literature without ISE focus, show that entrepreneur education positively impacts students' interest and motivation in entrepreneurship, and is effective in developing EM. Therefore, ISE educators should explore and implement strategies to expose their students to entrepreneurship in the curriculum. This will help equip ISE graduates with knowledge and skills that are in demand in the current job market. As discussed earlier, one approach to foster EM is to integrate entrepreneurship elements into the courses. The studies that are examples of this approach are listed in

Table 3. The publication dates in both tables show that putting EM into practice through ISE courses is gaining traction. However, in keeping with the trend observed in interest in EM in ISE education, this approach is also in early stages. The variety of courses despite the small sample size, however, is a depiction of how well EM aligns with ISE. Looking back to items shown in Table 1 and the areas in ISEBoK, finding relevance of EM in ISE courses is not difficult. Some example core courses, besides the ones already listed in Table 3, would be quality management, manufacturing analysis, operations research, production planning and control and human factors and ergonomics.

Table 2: The Role of EM in ISE Education

Authors	Contribution
L. Rabelo et al. (2006)	Introduces entrepreneurship as an emerging topic in IE curriculum
P. Resto et al (2007)	Discusses the importance of integrating innovation and entrepreneurship experience in higher education, especially in IE curriculum, and proposes entrepreneurship-driven IE
A. Yassine, C. Beck (2007)	Proposes the integration and fusion of business, technical and entrepreneurial aspects of engineering systems into the curriculum as opposed to taught as separate topics, and discusses new courses added the Systems Engineering program @ U. of Illinois at Urbana-Champaign: Systems & Entrepreneurial Engineering, Technology Innovation and Market Strategy, Technology Entrepreneurship
R. C. Engler et al. (2008)	Discusses bringing innovation and entrepreneurship in IE, emphasizes the importance of design thinking, defines intraprenuer without using the term
J. H. Wilck et al. (2011, 2012)	Explains IEs role in engineering entrepreneurship by bringing attention to Engineering Economics education in IE programs; discusses an entrepreneurship minor offered by the IE program
C. A. Yauch (2011)	Presents results of a four-year pilot study conducted in the IE program to assess students' interest in entrepreneurship. Findings indicate that IE students have a good understanding of the concept, but not necessarily interested in it. Recommends that IE educators should include more elements in the curriculum to expose students to entrepreneurship
A. Houshyar et al. (2014)	Describes the transformation of the IE program into Industrial and Entrepreneurial Engineering (IEE) program which include incorporation of three new courses with an emphasis on entrepreneurial engineering. The effort targets both entrepreneur and intrapreneurs
V. Barba-Sánchez, C. Atienza-Sahuquilloba (2017)	Presents the results of a study aimed to assess entrepreneurial intentions among engineering students and the effectiveness of entrepreneurial education in promoting interest in entrepreneurship. IE students constitute half of the study population. The results indicate that entrepreneurial education is significant in fostering motivation and interest in entrepreneurship

5. Conclusion

Industry expectations of engineering graduates are increasingly expanding with changing times and require knowledge and skills beyond discipline specific technical competencies. Possessing an EM which means having inquisitive thinking and desire to learn, ability to see relationships and how things fit together and be able to use these attributes in identifying opportunities and creating value in any context, is now highly valued. The ISE practice requires focus on customer and what they value, ability to see a system/process as a whole, and continuing consideration of ways to improve. Hence, the characteristics of an EM are clearly comparable to and compatible with the ISE practice. Nevertheless, the results of SLR conducted in this study shows that there is no coverage of entrepreneurship concepts and skills in ISE education in a structured or regular fashion. To equip ISE graduates with the knowledge and skills matching with today's industry expectations, the ISE educators should consider renovating the ISE curriculum with integrating elements that will foster EM. Examples of such integration in individual courses given in this paper can serve as a starting point to initiate discussions and inspire educators to critically review the existing curriculum.

Table 3: EM Deployment in ISE courses

Author; *Course*; EM Objectives; Activity Summary
J. Chen, Y. Li (2010); ***Facility Design***; Identifying opportunities, creating a business plan, analyzing the market
A course project involving a new facility design was renovated through introducing four modules covering the following: Module 1: Basic entrepreneurial concepts and skills such as opportunity recognition, developing a business model; Module 2: Feasibility studies with a focus on market analysis; Module 3: Techniques of facility planning and facility layout; Module 4: Business plan development. The renovations aimed to provide students an understanding of entrepreneurial process when pursing a new idea and starting a new business and an opportunity to apply what they learned. Module 1 & 2 get students think about the customer and the value of the potential new facility will bring. The actual project work is completed in Modules 3 & 4 during which the students design a facility layout and business plan for a product that was already identified for them. The work is completed in teams. The business plan which includes the description of the product, how it will be built, the details of the new facility, and a 12 month cash flow diagram is presented to a pretend loan officer.
P. C. Lynch et al. (2015, 2016a, 2016b); ***Engineering Economy****;* Develop, evaluate and communicate engineering solutions in economic terms
Financial account and finance topics were incorporated into the course to help students recognize the impact of engineering economic decisions on the business. In addition to the new lecture material, stock competition, case competitions and a real life company problem were introduced to help students practice economic cost benefit analysis and furthermore pitch their solutions to the company personnel.
J. A. Mallory et al. (2016); **Probability *& Statistics****;* Investigating the market, identifying opportunities, evaluating customer needs
A new assignment was added to the course that involved students conducting market research analysis to determine the best location for a new fabrication facility for producing alternative energy homes. The students were asked to use population growth data rate from census data and conduct statistical analysis to justify their location selections.
F. Ghazi-Nezami et al. (2016); ***Supply Chain***; Creative thinking, identifying opportunities, collaboration and communication skills
Course was renovated by adding three modules focusing on developing students' EM. In Module 1 students learn about demand forecasting, economic analysis and supplier selection through analyzing their own cellular data consumption and selecting a wireless plan. In Module 2 they practice idea generation, product planning and design methods through market study and customer identification and engagement. In Module 3 students learn energy management practices through gemba walks that help them identify energy saving opportunities on campus and analyzing a real data set from a manufacturing facility and proposing saving solutions.
M. E. Kuhl (2020); ***Systems Simulation****;* Identifying opportunities, creative thinking, value identification
Two activities were integrated into the course. Activity 1 aims to help students recognize the value of simulation in real life applications through literature review of application papers individually and in teams. Activity 2, which is an open-ended class project, helps students practice developing creative solutions and identifying and communicating the value through designing a system to transport theme park guests between multiple locations.

References

[1] Kauffman Foundation, "Entrepreneurship in American Higher Education: A Report from the Kauffman Panel on Entrepreneurship Curriculum in Higher Education", 2008.

[2] E.A. Aranha, P.H. Santos, N.A.P. Garcia, "EDLE: An integrated Tool For Fostering Entrepreneurial Skills Development in Engineering Education," *Educational Technology Research and Development*, vol. 66, pp. 1571-1599, August 2018.

[3] T. Byers, T. Seelig, S. Sheppard, P. Weilerstein, "Entrepreneurship: Its Role In Engineering Education.," *National Academy of Engineering The Bridge: Linking Engineering and Society, (Summer)*, vol. 43, no. 2, pp. 35–40, June 2013. Available: https://www.nae.edu/81235/Entrepreneurship-Its-Role-in-Engineering-Education [Accessed Jan 22, 20201].

[4] J.M. Bekki, M. Huerta, J.S. London, D. Melton, M. Vigeant, J. M. Williams, "Opinion: Why EM? The Potential Benefits of Instilling and Entrepreneurial Mindset", *Advances in Engineering Education*, (11 pages) Fall 2018.

[5] M. Archibald, M. Clauss, J. Dupree, "Entrepreneurship in Capstone Design using Interdisciplinary Teams and a Business Plan Competition," in *Proceedings of 2005 American Society for Engineering Education Conference*, Portland, OR. Available: https://peer.asee.org/15567. [Accessed Jan 22, 2021].

[6] J. Mallory, "A module to introduce the entrepreneurial mindset into thermodynamics – a core mechanical

engineering course" in *Proceedings of 2015 American Society of Engineering Education Conference*, Seattle, WA. Available: https://peer.asee.org/23410. [Accessed Jan 22, 2021].

[7] S.J.Gandhi, M.G. Beruvidas, S. Taghazadeh, J.A. Cross, "A Comprehensive Review of Entrepreneurship Course Offering in Engineering Programs," in *Proceedings of 2016 American Society for Engineering Education Conference Proceedings,* New Orleans, LA. Available: https://peer.asee.org/26295.[Accessed Jan 22, 2021].

[8] M. Schar, S. Sheppard, S. Brunhaver, M. Cuson, M. Grau, "Bending Moments to Business Models: Integrating an Entrepreneurship Case Study as Part of Core Mechanical Engineering Curriculum," in *Proceedings of 2013 American Society for Engineering Education Conference Proceedings,* Atlanta, GA. Available: https://peer.asee.org/19256. [Accessed Jan 22, 2021].

[9] N.O. Erdil, R.S. Harichandran, J. Nocito-Gobel, C.Q. Li, M. Carnasciali, "Impact of Integrated E-Learning Modules in Developing an Entrepreneurial Mindset based on Deployment at 25 Institutions," in *Proceedings of 2017 American Society of Engineering Education Conference,* Columbus, OH. https://peer.asee.org/28467. [Accessed Jan 22, 2021].

[10] KEEN, "What is the KEEN Framework?," https://www.engineeringunleashed.com/Mindset-Matters/Framework.aspx. [Accessed Jan 22, 2021].

[11] Institute of Industrial and Systems Engineers, "What is Industrial and Systems Engineering?," https://www.iise.org/details.aspx?id=282. [Accessed Jan 22, 2021].

[12] Y. Xiao, M. Watson, "Guidance on Conducting a Systematic Literature Review,' *Journal of Planning Education and Research*, vol.39, no, 1, pp.93-112, 2019.

[13] C. Okoli, "A Guide to Conducting a Standalone Systematic Literature Review," *Communications of the Association for Information Systems*, vol. 37, pp. 879-910, 2-15

[14] P. J. Purnell, "Conference Proceedings Publications in Bibliographic Databases: A Case Study of Countries in Southeast Asia," *Scientometrics*, Nov 2020.

[15] L. Rabelo, E. Hernandez, L. Crumpton-Young, H. Eskandari, S. Sala-Diakanda, S. Furterer, K. Williams, "Emerging Topics For Industrial Engineering Curriculum," in *Proceedings of 2006 American Society of Engineering Education Conferenc,* Chicago, IL. https://peer.asee.org/1452. [Accessed Jan 22, 2021].

[16] P. Resto, D. Gonzales, A. Rullan, M. Padron, "Entrepreneurship-Driven IE as Response to the Flat World," in *Proceedings of 2007 Industrial and Systems Engineering Research Conference*, Nashville, TN., May 19-23, 2007, pp. 60-63.

[17] A.Yassine, C. Beck, "The Systems Engineering Program at the University of Illinois at Urbana-Champaign," in *Proceedings of 2007 Industrial and Systems Engineering Research Conference*, Nashville, TN, USA, May 21-23, 2007, pp. 100-103.

[18] J. Chen, Y. Li, "Incorporating Entrepreneurship into a Hands-on Facility Planning Course," in *Proceedings of 2010 American Society of Engineering Education Conference,* Louisville, KT, USA. https://peer.asee.org/16717. [Accessed Jan 22, 2021].

[19] J. Wilck, H.L. Martin, X. Li, E.S. Sawhney, G.P. Rajappa, "Initial Results from Engineering Entrepreneurship Minor within Industrial Engineering Curriculum," in *Proceedings of 2011 Industrial and Systems Engineering Research Conference*, Reno, NV, USA, May 21-25, 2011.

[20] M. A. C. Pereria, M.B. Silva, "Planning the Development of Competences in an Industrial Engineering Curriculum," in *Proceedings of 2014 Industrial and Systems Engineering Research Conference*, Montreal, Canada, May 31-Jun 3, 2014, pp. 1639-1648.

[21] A.Houshyar, B.White, S.E.Butt, T.K.Fredericks, "Development and Implementation of the Industrial and Entrepreneurial Engineering Program at Western Michigan University," in *Proceedings of 2014 American Society of Engineering Education Conference,* Indianapolis, IN. https://cms.jee.org/20302.[Accessed Jan 22, 2021].

[22] P. C. Lynch, C. Bober, J. Wilck, "An Integrated Approach to Developing Business Expertise in Industrial Engineering Students," in *Proceedings of 2015 American Society of Engineering Education Conference,* Seattle, WA, USA. https://peer.asee.org/23530. [Accessed Jan 22, 2021].

[23] J.A. Mallory, M. Romoser, M.J. Rust, T. Keyser, "Inclusion of Entrepreneurially Minded Learning (EML) Modules in 2nd Year Core Engineering Courses," in *Proceedings of 2016 American Society of Engineering Education Conference,* New Orleans, LA, USA. https://peer.asee.org/25644. [Accessed Jan 22, 2021].

[24] F. Ghazi-Nezami, M. S. Tavakoli, M. Torfeh, "Developing Entrepreneurial Mindset in Industrial Engineering Classes: A Case Study,"in *Proceedings of 2016 American Society of Engineering Education Conference,* New Orleans, LA, USA. https://peer.asee.org/26756. [Accessed Jan 22, 2021].

[25] M.E. Kuhl, "Fostering an Entrepreneurial Mindset in Systems Simulation,"in *Proceedings of 2020 St. Lawrence Section Meeting, ASEE,* Rochester, NY, USA. https://peer.asee.org/33904. [Accessed Jan 22, 2021].