

A Review of Entrepreneurial Concepts in Mechanical Engineering Education

Prof. John Reap, Quinnipiac University

As one of Quinnipiac University's School of Computing and Engineering's Founding Faculty members, John Reap helped shape, foster and guide its undergraduate focused engineering school since its founding in 2012. Educating undergraduate mechanical engineers remains one of this primary career foci. His scholarly activities are rooted in engineering design with an emphasis on environmentally benign / sustainable design and manufacturing. He also possesses a growing interest in engineering education, especially with regards to environmental sustainability and entrepreneurial innovation in the curriculum.

A Review of Entrepreneurial Concepts in Mechanical Engineering Education

Abstract

Entrepreneurship increasingly finds a place in engineering education. Focusing on mechanical and closely allied disciplines, this article reviews literature describing entrepreneurial concepts in engineering education. Conventional and newer search techniques identify relevant publications, and then, this work discusses the manifestations and prevalence of entrepreneurial concepts. It identifies motivations for including these concepts and discusses the potential for underlying drivers of their appearance. It further categorizes types of entrepreneurial activity that one encounters in the literature.

To identify both manifestations and prevalence of entrepreneurial concepts, the search method uses a mix of traditional academic databases and artificial intelligence (AI) tools to explore the engineering education literature. These tools find examples of manifestations from which one notes distinct terms such as entrepreneurial mindset learning (EML). The frequency of these key terms provides an indication of the prevalence of various manifestations.

Qualitative examination of examples of the identified manifestations leads to insights concerning the motivations behind inclusion of entrepreneurial concepts in mechanical engineering education. The work summarizes these motivations. Then, it discusses those motivations in the context of potential underlying drivers such as enhanced realism in education, better connection to the engineering design process, and maximization of the value of education.

Finally, the work categorizes the major forms of entrepreneurial intervention in mechanical and closely related engineering curriculums. The extent of interventions (i.e. modules within courses vs. more extensive curricular incorporation) is noted. The article interrogates the notion that entrepreneurial curriculum elements take the form of business creation, innovation facilitation, or development of targeted mental habits.

Keywords

Mechanical Engineering, Entrepreneurship, Entrepreneurial Mindset, Curriculum, Pedagogy

Introduction

Entrepreneurship increasingly finds a place in engineering education. This article describes a bounded portion of that place as it currently exists, and it further apprehends the forces that shape manifestation of entrepreneurial thought in engineering curricula. The article discusses current applications of entrepreneurial ideas in engineering education, and it targets the curricula of mechanical engineering and allied disciplines. These twin bounds focus the work. The former prevents ungrounded discussions of hypothetical applications. The latter permits a concise yet thorough treatment of the topic.

To chart the intersection's topography, the article reviews literature describing entrepreneurial concepts in engineering education. Questions regarding entrepreneurship's use drive this review.

How have engineering educators sought to incorporate entrepreneurial concepts into mechanical engineering and related curricula? What motivates incorporation? Which beliefs underly those motivations and drive these developments? Traditional and AI assisted literature survey techniques provide qualitative and basic quantitative answers to these questions in the following sections.

Entrepreneurial Concepts in Mechanical Engineering Curricula – Traditional Survey

A traditional review of literature finds three general ways in which entrepreneurial concepts manifest in mechanical engineering curricula. The first centers on the business aspects of entrepreneurship. Technical work and innovation remain important, but the needs of an existing, potential, or simulated enterprise coordinate the student experience and manifestation in the curriculum. A second way focuses on the thought process and attitudes that accompany entrepreneurial activity. This approach often manifests as engineering problems, whether old or new, that curricular structures encourage students to approach with an entrepreneurial mindset. The creation or support of a business enterprise, while still welcome, is a secondary concern. Measuring entrepreneurial aspects of engineering students stands as a third, though far less prominent, way in which entrepreneurial concepts influence curricula. Here, educators propose and test psychometric instruments to establish baselines and gauge changes in entrepreneurial mindset or intent.

Educational literature on mechanical and closely adjacent engineering contains multiple instances where the business of entrepreneurship serves as the center of a curricular intervention. The enterprise in question may exist as a simulation, a potential enterprise, or a functioning business in such cases. Costello simulates "...real-life entrepreneur interaction for students..." by requiring final year mechanical engineering students to solve class design problems in collaboration with real entrepreneurs [1]. As an interaction between business students with entrepreneurial intent and sophomore mechanical engineering CAD students shows, simulation of entrepreneurial activity may also occur earlier in the ME curriculum [2]. Pre and post student surveys show no statistically significant change in entrepreneurial affects resulting from this interaction, though. Unsurprisingly, the literature holds examples of pedagogy meant to encourage potential enterprises based on engineering innovation. Wang and Kleepe describe a capstone course for ME and EE seniors that incorporates legal, financial and venture capital considerations alongside engineering prototyping as part of an effort to develop a new product [3]. Their qualitative and quantitative assessments of the educational intervention found that it met their learning objectives using a format desired by their students. Moreover, the intervention imparted skills that employers found beneficial, "...as alumni often find themselves in key positions in their workplace due to the additional knowledge they gained from the course" [3]. A Stony Brook University led capstone course sequence possesses a similar purpose of completing a functional sensor based medical device prototype containing an "original patentable idea" which could lead to "...entrepreneurial development and commercialization..." [4]. Start-up creation, with its attendant focus on business processes and prototyping, drives a two semester capstone course open to mechanical engineering technology (MET) students [5]. A three course sequence for graduate engineering and business students aims to generate new products, develop businesses around them and launch the businesses after successfully securing external funding [6]. Efforts to support start-up activities for senior MEs exist on university campuses outside the US, as Pradeep's description of entrepreneurial support on APJ Abdul Kalam Technological

University in India shows [7]. Entrepreneurial activities also enter the engineering curriculum with the support of existing businesses. The presence of market identification and business plan development differentiate traditional and entrepreneurial capstone projects in such cases [8]. Creed's two course sequence meant to design prototypes and generate associated business plans for committed corporate sponsors serves as an example [9]. Efforts in the United Kingdom led to a multi-year enterprise education process for one mechanical engineering department [10]. Students take a business skills class emphasizing market, financial and intellectual property assessments in their second year, and then, they attempt to solve and present a business case for their solution to an existing enterprise's problem during a capstone design course.

A focus on general thought processes and attitudes associated with entrepreneurship stands as the second general manifestation of entrepreneurship in mechanical and closely related engineering curricula. A term for these thought processes and attitudes found in some sources is entrepreneurial mindset (EM). Problem based learning (PBL) in some form occurs in all observed instances of interventions meant to promote EM as a diversity of examples shows. A mechanical engineering thermodynamics course with a competitive, team-based power plant design project that considers economic and environmental factors explicitly imbeds a conceptualization of EM in its structure [11]. An assistive device design project in a one semester machine design course demonstrates another variation on EM development [12]. In that course, curiosity, connection and creation of value (the 3Cs of EM promoted by KEEN: Kern Entrepreneurial Engineering Network) serve as explicit modules that guide students through introduction and development of the project. Student survey results show increases in those three dimensions between the first (2021) and second (2022) offerings of the course [12]. However, given the assessment design, one cannot know the base state of the students before the course or if non-entrepreneurial factors led to the changes between the years. Cioc and coworkers pilot offering of a fluid mechanics course for senior mechanical engineering technology students embeds EM concepts in small projects [13], [14]. They report desirable achievement of content knowledge and improvement in soft skills related to EM. However, the direct assessments used to evaluate content knowledge only provide data for this initial offering, and statistically significant improvements with EM were confined to items related to creation of value and connecting decisions with consequences [13]. A mechatronics project offered to senior and junior MEs using "scaffold-learning" and "hands-on learning" appears to enhance their EM abilities [15]. A three course project sequence for mechanical engineering students uses SAE vehicle design and industry projects with EM learning objectives in each course [16]. These learning objectives follow from the KEEN framework [17]. The developers of the sequence believe students, "...exhibit many example behaviors associated with an entrepreneurial mindset..." but comparing survey data from the start and the end of the sequence, the authors admit that clear statistical evidence for improvement in EM is lacking [16]. Liu and coauthors describe a gantry crane design problem that students noteworthy revisit in three different mechanical courses (fluid mechanics, heat transfer and mechatronics) [18]. They provide survey evidence that, as intended, completion of the revisited project improved skills associated with EM such as teamwork, integration of information and the creative solution of ambiguous problems.

Measurement of mental attributes associated with entrepreneurship exists as a third way that this topic enters the engineering curriculum. While researchers who wish to enhance EM abilities typically use some post intervention assessment, some only evaluate abilities associated with EM

as students progress in a curriculum. Brunhaver and coauthors, for instance, describe development of a survey instrument for assessing multiple EM abilities rooted in KEEN’s 3Cs [19]. They administer this survey to a cohort of freshmen engineering students with a plurality of mechanical engineering students. Duval-Couetil and coworkers probe the attitudes toward and effects of entrepreneurship education on engineering seniors in capstone courses [20]. Some target particular EM skills such as opportunity recognition in ME seniors taking a design course [21]. Others examine the attributes that might presage business formation among science and engineering students [22].

Entrepreneurial Concepts in Mechanical Engineering Curricula – AI Summary

Three prompts fed to Google’s Gemini 1.5 Flash artificial intelligence tool generated output meant to compliment the traditional literature survey concerning the intersection between entrepreneurship and engineering education. The first prompt asks Gemini 1.5 Flash to identify and categorize entrepreneurial concepts appearing in university mechanical engineering curricula. The second requests associated keywords, and the third requires identification of motivations for incorporation of entrepreneurship. All prompts constrain Gemini to use peer reviewed sources. Unedited AI output appears in supplemental material (See Appendix A). This section summarizes Gemini 1.5’s primary responses and closes with commentary on the credibility of the AI output.

According to Gemini 1.5, entrepreneurial ideas appear in the mechanical engineering curriculum as project-based design courses, courses on creativity and design thinking, and dedicated business skills courses tailored to technologists. These courses possess a scope beyond the traditional remit of solving a technical problem and estimating its direct cost. They simulate product development cycles with market need identification, market research, business plan development, design, iterative prototyping, protection of intellectual property and consideration of broader matters such as sustainability. Such courses emphasize teamwork; engineering students often work in multidisciplinary teams that include business students. The AI summary also notes that entrepreneurial activity enters the engineering school experience in the form of incubators and accelerators that assist in start-up creation or generally help students move ideas toward commercialization.

While the AI provides multiple keyword sets, one discerns three general categories of keywords: design thinking & activity, business topics and technology. Table 1 gives a sampling for all three categories.

Table 1: Sample of AI Identified Keywords for Entrepreneurship in Mechanical Engineering Curricula

Category	Keywords
Design Thinking & Activity	Ideation techniques, iterative development, creative problem-solving, design projects, problem-based learning
Business Topics	Intellectual property, startups, venture capital, business plans, financial modeling, market research, leadership, teamwork
Technology	Additive manufacturing, robotics & automation, renewable energy, medical devices

The response to the third prompt concerning motivation identifies four general reasons to incorporate entrepreneurship in mechanical engineering curricula. Increasing the workforce readiness of graduates stands as the first reason. The claim is that these experiences improve problem solving, the ability to adapt, consideration of broader perspectives and pursuit of identified opportunities. Enhanced engagement in the learning process is a second reason. The real-world problems that typically form the core of entrepreneurial experiences in engineering give students a chance to apply theoretical knowledge in relevant contexts. Not surprisingly, the potential for innovation and new technology provides a third, major motivation. The “culture of innovation” that accompanies such efforts is thought to develop iterative learning, risk-taking, continuous improvement and a better grasp of the design process. In a related fashion, the potential for tangible economic, social and environmental impact provided by entrepreneurial activity yields a final motivation. Student entrepreneurs may form businesses or social enterprises that create jobs, promote economic growth, or address broader challenges (i.e. climate change).

Value of Artificial Intelligence

Artificial Intelligence contributes value in the context of this literature review in two general ways. First, it serves as a check for completeness. A major category appearing in the AI content yet missing from the traditional survey points to an area that needs further investigation. The categories found using traditional and AI surveys broadly agree in this work; so, one gains a level of confidence that this work addresses the outstanding topic areas. Generation of related subtopics in identified categories stands as a second form of value. Especially with AI results from the first prompt, one finds subcategories and examples of entrepreneurial ideas in the mechanical engineering curriculum that require substantial time to manually extract from publications and to organize into a coherent structure. For instance, an educator wishing to add elements of entrepreneurial thinking to his course or outline an entrepreneurial minor suited for mechanical engineers rapidly gains insights for both activities when reviewing the AI generated outline.

Credibility of Artificial Intelligence

When using AI generated content, one must confront credibility concerns. Is the AI presenting a limited or skewed representation of available information? Worse still, is the AI generating erroneous outputs (i.e. hallucinating)? Two means of evaluating AI’s credibility exist in this work. The first relies on the guidance of AI researchers with an interest in the topic of AI credibility. The second is the direct comparison of AI output to traditional literature survey results found in the section immediately proceeding the one AI.

Evaluating the trustworthiness of outputs from recently developed AI tools is a quite new challenge that research communities are just now forming to address [23]. An investigation of AI accuracy found that ChatGPT 3.5 proved, “...generally good at writing concept topics...”[24]. One reasonably classifies a literature survey task as a concept topic, suggesting the potential for accurate results from AI. However, this work uses Gemini 1.5 Flash, not ChatGPT 3.5. Verhulsdonck and coauthors introduce a subjective means of evaluating the accuracy of AI generated content independent of the particular tool [24]. Their HEAT method, an acronym formed from Human experience, Expertise, Accuracy and Trust, attempts to

subjectively gage AI output credibility. In this work's contents, the H and E terms might best refer to the correspondence of AI outputs with human physical and mental experience. This author's prior published [2] and unpublished work with entrepreneurial activity in an educational context provides the experience that one may compare with AI outputs. The AI outputs appear broadly in line with this author's experience, though the AI's emphasis on biomedical and sustainability topics is somewhat surprising. The A and T elements require something beyond experience for comparison.

The results of the traditional literature survey serve as one such object. Once again, a comparison reveals that both the traditional survey and the AI output identify similar themes. Entrepreneurial interventions in engineering take the form of modified design courses, additional business topics and attempts to facilitate start-up activity. The motivations for the interventions correspond as well. Both exploration approaches reveal a desire to improve the learning process or promote business creation centered on innovation. The AI results, therefore, appear generally credible, but some of the specific examples (i.e. biomedical and sustainability examples) may suggest a certain bias toward those topics. Those topics appear in the traditional survey, but the second prompt, the one requesting keywords, leads Gemini 1.5 Flash to generate six of ten keywords related to biomedical and sustainable topics in the Mechanical Engineering Specifics section (See Appendix A). Though worthy and important areas of applied work in mechanical engineering, 60% dominance of mechanical engineering focused entrepreneurial activity by those topics seems unlikely when one considers opportunities for robotics, the internet of things, and more.

Prevalence of Entrepreneurial Ideas in Engineering Literature

Searches of academic databases using relevant, commonly observed terms from the prior portion of the traditional review gage the prevalence of entrepreneurial concepts in engineering literature. Constrained to only peer reviewed sources, the number of times a specific set of terms appears as a result of a query quantifies prevalence. This review utilizes OneSearch, a tool that searches nearly all Quinnipiac University Library holdings, subscribed databases, journals and other sources [25]. These queries target only abstracts and subject term lists. Queries in OneSearch access the Educational Resources Information Center (ERIC) database, a comprehensive source for education research. To counter any biases in the selection of sources linked to OneSearch, execution of a similar query occurs using the WorldCat database which allows exploration of holdings at over 10,000 other libraries. These queries target only subject term and keyword lists.

Table 2 shows the prevalence of peer reviewed entrepreneurship investigation in engineering and, specifically, mechanical engineering literature. For comparison, querying entrepreneurship using OneSearch yields 152,096 peer reviewed results, and with WorldCat, the number is 139,103. Literature on engineering entrepreneurship appears to constitute somewhere between ~1.7 – 8% of the entrepreneurship literature when comparing the first column of Table 2 to these data. If one compares articles on mechanical engineering entrepreneurship to peer reviewed work in mechanical engineering, the percentage of the former is vanishingly small. However, even these numbers may overstate the discussion of entrepreneurial ideas in engineering education literature. An abstract-by-abstract examination of the 43 peer reviewed references identified by OneSearch using the query *mechanical engineering, entrepreneurship* finds that

only 12 of them consider entrepreneurship in the educational process. The majority include the search terms, but they discuss matters other than entrepreneurship in mechanical engineering education.

Table 2: Search Result Numbers for Queries of OneSearch and WorldCat Database Search Tools

Queries	OneSearch Frequency	WorldCat Frequency
Engineering, entrepreneurship	2630	11638
Engineering, problem-based learning	2262	1198
Engineering, entrepreneurship, curriculum	259	889
Engineering, entrepreneurial mindset	100	53
Engineering, entrepreneurship, problem-based learning	13	23
Engineering, entrepreneurial mindset, curriculum	9	5
Engineering, entrepreneurial mindset, pedagogy	4	1
Mech. engineering, entrepreneurship	43	140
Mech. engineering, problem-based learning	45	36
Mech. engineering, entrepreneurship, curriculum	2	5
Mech. engineering, entrepreneurial mindset	0	4
Mech. engineering, entrepreneurship, problem-based learning	0	1
Mech. engineering, entrepreneurial mindset, curriculum	0	0
Mech. engineering, entrepreneurial mindset, pedagogy	0	0

Discussion – Motivations and Drivers

Motivations for developing various entrepreneurial education concepts in mechanical engineering, and engineering more generally, divide between skill improvement and business development. One finds that beliefs held by engineering educators and supporting organizations mirror these two categories and drive their development.

Improvement or expansion of engineering students' skill set appears as a primary motivation in many of the consulted sources [1], [9], [11]-[16], [18]. Educators reveal the centrality of this motivation when stating a hope to improve "...technical and soft skills..." [14] and "...increase student design, project management and communication skills..." [16]. This finding is consistent with the first two motivations identified by Gemini 1.5 Flash: workforce readiness and engagement. In fact, "...readiness for the engineering profession..."[13] and an "...increase in student engagement..." [11] appear as explicit goals in some sources.

While not fully discounting learning as a goal in an educational setting, some form of business development serves as the essential motivation for other manifestations of entrepreneurship in engineering [3], [5]-[7], [10]. In these cases, the stated goal of combining entrepreneurial ideas with engineering education may take the form of a general desire to "...increase enterprise learning and entrepreneurship..." [10], or it may narrow to one where students, "...learn about,

actively participate in, and form small scale startups...” [5]. This, too, is consistent with the third and fourth motivations previously provided by Gemini 1.5 Flash: technology development and business formation. Gemini 1.5 highlights technology and businesses with broader social impacts (i.e. healthcare), and it is noteworthy that a medical device based project meant to generate an, “...original, patentable idea...,” appears in the traditionally collected literature [4].

Abstracting back from proximate reasons, one might wonder about the drivers of the motivations, the beliefs of individuals and organizations creating the concepts appearing in reviewed literature. Hixon and Paretti use Activity Theory [26] to explore the beliefs of entrepreneurially experienced engineering educators who introduced entrepreneurial thinking into their academic practice [27]. Their interviews of 18 academics identify three reasons for the academics’ incorporation of entrepreneurial thinking: increased impact of their research on society, improved student academic preparation, and enhanced student interest and success. The second of these beliefs directly maps to the previously discussed motivation of improving student skill sets. The first and third beliefs best map to the second motivation, especially when one considers the broader impact potential of enterprise that addresses unmet social needs. Hixon and Paretti observe that the interviewed faculty experiences move them, “...beyond publishing papers and toward developing discoveries that impact the world...” [27]. They further observe, with respect to student interest and success, that entrepreneurial skills, “...open doors for corporate partnerships...” and that students express a desire to form ventures or seek advice concerning projects after exposure to entrepreneurial thinking [27].

Noteworthy organizations drive development of entrepreneurial education in engineering as well. Supported by the Kern Family Foundation, the Kern Entrepreneurial Engineering Network (KEEN) exists to enhance entrepreneurial mindset (EM) among undergraduate engineering students [28]. KEEN defines EM in terms of its 3Cs of curiosity, connections and creating value, which further subdivide into specific activities [17]. Instilling EM alongside an engineering skillset is believed to enhance the capability of engineering students [17]; therefore, organizations such as KEEN are drivers of the first motivation for integrating entrepreneurship in engineering education. VentureWell, originally founded as the National Collegiate Inventors and Innovators Alliance (NCIIA), supports university courses and programs that bring inventions to market and, more broadly, “...student innovations to the world” [29]. The prolific American inventor Jerome “Jerry” Lemelson prompted the formation of VentureWell in 1995. As presented by the Lemelson Foundation, Lemelson held an abiding faith in the capacity for invention to address challenges and improve lives [30]. The second motivation focused on venture creation reveals the influence of organizations such as Lemelson’s VentureWell.

Closure

The presented traditional and artificial intelligence assisted literature review explores the influence of entrepreneurial ideas on mechanical and, to a lesser extent, general engineering education. It contributes an overview of concepts used to incorporate entrepreneurial ideas into mechanical engineering education, briefly noting their effectiveness where assessment evidence exists. This work further categorizes these concepts, and it discusses motivations and drivers of these entrepreneurial concepts.

Entrepreneurial concepts typically enter the curriculum in design projects, especially capstone projects, spanning 1-3 courses. Modules and smaller scale projects in core courses appear to a lesser extent. Assessment of these interventions in the curriculum, where present, vary in comprehensiveness, and even for assessed measures, one finds outcomes ranging from positive to no significant impact.

These concepts center on either the business aspects of entrepreneurship or attitudes and thought processes that accompany entrepreneurial activity, often referred to as entrepreneurial mindset. The potential to form business ventures that transfer innovations to market motivates the former. A desire to enhance engineering education quality motivates the latter. Beliefs of engineering faculty as well as external supporting organizations serve as underlying drivers for both motivations, though some privilege one motivation over the other. The varying impact of different concepts coupled with differences in focus presents opportunities for identification of best practice entrepreneurial interventions and assessment tools that account for the two aims.

Limitations on these observations stem from the focus on mechanical and related engineering as well as the focus on engineering education literature. Though deliberately targeted to yield insight into mechanical engineering curricula, this approach overlooks educational developments in business and other disciplines that may prove relevant to mechanical engineering. Targeted, future reviews of other engineering disciplines can complete the picture while generating an opportunity for comparisons. The low prevalence of education publications simultaneously dealing with mechanical engineering and entrepreneurship possibly understates activity in this topical area, and consequently, the available sample may not fully capture entrepreneurial concepts in mechanical engineering curricula. Future surveys of mechanical engineering departments on these topics would provide primary data that could confirm or add to the presented observations.

References

- [1] G. J. Costello, "More than just a game: the role of simulation in the teaching of product design and entrepreneurship to mechanical engineering students," *European Journal of Engineering Education*, vol. 42, (6), pp. 644–652, 2016. DOI: 10.1080/03043797.2016.1211992.
- [2] J. Reap and D. Tomczyk, "Changes in affective capacities of CAD students engaged in an engineering design project," in *ASEE Annual Conference & Exposition*, 2023, pp. 1–15.
- [3] E. L. Wang and J. A. Kleppe, "Teaching Invention, Innovation, and Entrepreneurship in Engineering," *Journal of Engineering Education*, pp. 565–570, 2001. DOI: 10.1002/j.2168-9830.2001.tb00640.x.
- [4] S. Luryi *et al*, "Entrepreneurship in engineering education," in *Frontiers in Education Conference*, 2007, pp. 1–6.
- [5] R. D. Webster and R. Kopp, "Case Study Of A Small Scale Polytechnic Entrepreneurship Capstone Course Sequence," *American Journal of Engineering Education*, vol. 8, (1), pp. 35–44, 2017. Available: <https://www.proquest.com/docview/1911760996>. DOI: 10.19030/ajee.v8i1.9965.
- [6] M. I. Mendelson *et al*, "Entrepreneurship in a Graduate Engineering Program*," *Journal of Engineering Education*, vol. 90, (4), pp. 601–607, 2001. . DOI: 10.1002/j.2168-9830.2001.tb00646.x.
- [7] M. Pradeep and K. P. Satish, "A campus start-up ecosystem for mechanical engineering students: Challenges, approaches, catalysts and solutions," *Industry and Higher Education*, vol. 36, (1), pp. 104–112, 2022. DOI: 10.1177/09504222211001785.
- [8] A. Shartrand and P. Weilerstein, "Strategies to Promote Entrepreneurial Learning in Engineering Capstone Courses," *International Journal of Engineering Education*, vol. 27, (6), pp. 1186–1191, 2012.
- [9] C. J. Creed, E. M. Suuberg and G. P. Crawford, "Engineering Entrepreneurship: An Example of A Paradigm Shift in Engineering Education," *Journal of Engineering Education*, vol. 91, (2), pp. 185–195, 2002.
- [10] R. D. Handscombe, E. Rodriguez-Falcon and E. A. Patterson, "Embedding Enterprise in Engineering," *International Journal of Mechanical Engineering Education*, vol. 37, (4), pp. 263–274, 2009. Available: <https://journals.sagepub.com/doi/full/10.7227/IJMEE.37.4.1>. DOI: 10.7227/IJMEE.37.4.1.
- [11] J. A. Mallory, "A module to introduce the entrepreneurial mindset into thermodynamics a core mechanical engineering course," in *ASEE Annual Conference & Exposition*, 2015, pp. 1–12.

- [12] J. A. Gargac, "Building Entrepreneurial Mindset: Motivating Curiosity, Connections, and Creating Value in an Assistive-Device Design Project," *Journal of Biomechanical Engineering*, vol. 146, pp. 1–5, 2024. DOI: 10.1115/1.4064520].
- [13] C. Cioc, N. A. Haughton and S. Cioc, "Combining problem-based learning with the KEEN's framework for entrepreneurially minded learning in a fluid mechanics course: Pilot implementation," in *ASEE 2022 Annual Conference & Exposition*, 2022, pp. 1–17.
- [14] C. Cioc, N. A. Haughton and S. Cioc, "Blending the entrepreneurial mindset into a learning module with a HVAC design project: Pilot implementation," in *ASEE 2022 Annual Conference & Exposition*, 2022, pp. 1–18.
- [15] V. Vijayan *et al*, "Impact of scaffolding and hands-on assignments within mechatronics on student learning outcomes of KEEN's entrepreneurial mindset," *International Journal of Mechanical Engineering Education*, pp. 1–28, 2024. DOI: 10.1177/03064190241240463.
- [16] J. A. Mynderse *et al*, "Development of an entrepreneurial mind-set within a three-semester mechanical engineering capstone design sequence based on the SAE collegiate design series," in *ASEE Annual Conference & Exposition*, 2019, pp. 9496–9513.
- [17] Kern Family Foundation, "The KEEN Framework: A Guide for Entrepreneurial Mindset,".
- [18] L. Liu *et al*, "Fostering the entrepreneurial mindset in the junior and senior mechanical engineering curriculum with a multi-course problem-based learning experience," in *Frontiers in Education Conference, FIE*, 2015.
- [19] S. R. Brunhaver *et al*, "Advances in Engineering Education Development of the Engineering Student Entrepreneurial Mindset Assessment (ESEMA)," *Advances in Engineering Education*, pp. 1–12, 2018.
- [20] N. Duval-Couetil, T. Reed-Rhoads and S. Haghighi, "Engineering Students and Entrepreneurship Education: Involvement, Attitudes and Outcomes," *International Journal of Engineering Education*, vol. 28, (2), pp. 425–435, 2012.
- [21] P. Shekhar *et al*, "Investigating mechanical engineering students' approaches to opportunity recognition process," *International Journal of Mechanical Engineering Education*, vol. 52, (1), pp. 43–62, 2024. Available: <https://doi.org/10.1177/03064190231169129>. DOI: 10.1177/03064190231169129.
- [22] V. Souitaris, S. Zerbinati and A. Al-Laham, "Do entrepreneurship programmes raise entrepreneurial intention of science and engineering students? The effect of learning, inspiration and resources," *Journal of Business Venturing*, vol. 22, pp. 566–591, 2007.
- [23] J. Mattioli and B. Braunschweig, "AITA: AI trustworthiness assessment," *AI Magazine*, vol. 44, (2), pp. 202, 2023. DOI: 10.1002/aaai.12096.

- [24] G. Verhulsdonck *et al*, "Incorporating Human Judgment in AI-Assisted Content Development: The HEAT Heuristic," *Tech. Comm.*, vol. 71, (3), pp. 60, 2024. . DOI: 10.55177/tc286621.
- [25] M. Flaherty. (Sep. 12). Q. *What does OneSearch search?*. Available: <https://libanswers.quinnipiac.edu/abl/faq/411035>.
- [26] Y. Engeström, *Learning by Expanding : An Activity-Theoretical Approach to Developmental Research*. 1987.
- [27] C. Hixson and M. C. Paretti, "Unpacking Why Engineering Faculty Members Believe Entrepreneurship Is Valuable for Engineering Education," *Advances in Engineering Education*, vol. 7, (1), pp. 1–11, 2018.
- [28] Kern Family Foundation. *KEEN: Kern Entrepreneurial Engineering Network*. Available: <https://engineeringunleashed.com/what-is-keen>.
- [29] VentureWell. *history*. Available: <https://venturewell.org/history/>.
- [30] The Lemelson Foundation. *The Lemelson Foundation*. Available: <https://www.lemelson.org/>.

Appendix A: AI Output for Prompts

Prompt: In what ways do entrepreneurship or entrepreneurial concepts appear in mechanical engineering curricula found in colleges and universities? Categorize these uses. Use peer reviewed academic sources when generating a response.

AI Output for Google. Gemini 1.5 Flash. Jan. 5, 2025. <https://gemini.google.com/>

Entrepreneurial concepts are increasingly integrated into mechanical engineering curricula, reflecting the evolving needs of the industry and the desire to foster innovation. Here's a categorization of how these concepts appear:

1. Design Thinking & Innovation:

- Product Development:
 - Focus: Emphasis on user-centered design, iterative prototyping, and rapid experimentation.
 - Courses: Design courses, often project-based, that simulate real-world product development cycles. Students learn to identify market needs, develop innovative solutions, and consider factors like manufacturability, cost, and sustainability.
 - Example: A course where students design and prototype a new prosthetic device, considering user needs, manufacturability, and potential market impact.
- Creativity & Ideation:
 - Focus: Cultivating creative problem-solving skills, brainstorming techniques, and developing a "mindset of invention."
 - Courses: May include dedicated courses on creativity, innovation, or design thinking, or be integrated into existing engineering courses.
 - Example: A course that explores biomimicry, encouraging students to find inspiration in nature to solve engineering challenges.

2. Entrepreneurship & Business Fundamentals:

- Technology Commercialization:
 - Focus: Understanding the process of bringing a new technology to market, including intellectual property protection (patents, trademarks), licensing, and venture capital.
 - Courses: May include dedicated courses on technology entrepreneurship, intellectual property, or business planning.

- Example: A course where students develop a business plan for a new medical device they have designed, considering market analysis, financial projections, and potential investors.
- Business Model Development:
 - Focus: Understanding different business models (e.g., subscription, licensing, platform), identifying revenue streams, and developing a sustainable business strategy.
 - Courses: May be integrated into design courses or offered as standalone electives.
 - Example: A course where students analyze the business models of successful technology companies and apply those concepts to their own engineering projects.

3. Experiential Learning & Real-World Application:

- Capstone Projects:
 - Focus: Often involve developing a product or system from concept to prototype, including market research, design, prototyping, and even potential commercialization.
 - Example: A senior design project where students design and build a low-cost, energy-efficient water purification system for developing countries, considering the potential for social impact and potential business ventures.
- Incubators & Accelerators:
 - Focus: Providing students with resources and mentorship to develop their entrepreneurial ideas.
 - Example: University-based incubators or accelerators that offer workspace, mentorship, and funding opportunities for student startups.

4. Interdisciplinary Collaboration:

- Teamwork & Communication:
 - Focus: Developing strong communication and teamwork skills, essential for successful entrepreneurship.
 - Courses: Many engineering courses emphasize teamwork, but specific courses on communication and leadership may also be included.

- Example: Project-based courses that require students to work in interdisciplinary teams with business students, designers, and other stakeholders.

Peer-Reviewed Sources:

- Articles in academic journals like:
 - *Journal of Engineering Education*
 - *IEEE Transactions on Education*
 - *International Journal of Engineering Education*
- Conference proceedings from engineering education conferences

Note: The specific integration of entrepreneurial concepts varies significantly between universities and departments.

Prompt: Which key words are associated with the appearance of entrepreneurship or entrepreneurial concepts in mechanical engineering curricula found in colleges and universities? Use peer reviewed academic sources when generating a response.

AI Output for Google. Gemini 1.5 Flash. Jan. 5, 2025. <https://gemini.google.com/>

Core Entrepreneurial Concepts:

- Innovation: This is foundational. Look for terms like:
 - Creative Problem-Solving
 - Design Thinking
 - User-Centered Design
 - Ideation Techniques
 - Rapid Prototyping
 - Iterative Development
- Technology Commercialization:
 - Intellectual Property (IP)
 - Patents

- Licensing
 - Venture Capital
 - Startups
 - New Venture Development
- Business Fundamentals:
 - Business Plans
 - Market Research
 - Financial Modeling
 - Marketing
 - Sales
 - Revenue Models
 - Sustainability

Experiential Learning:

- Capstone Projects:
 - Design Projects
 - Project-Based Learning
 - Industry Collaborations
 - Real-World Applications
- Incubators & Accelerators:
 - Entrepreneurship Centers
 - Innovation Hubs
 - Mentorship Programs

Interdisciplinary Focus:

- Interdisciplinary Teams
 - Collaboration

- Communication
- Leadership
- Teamwork
- Cross-functional Skills

Mechanical Engineering Specifics:

- Advanced Manufacturing:
 - Additive Manufacturing (3D Printing)
 - Robotics & Automation
 - Mechatronics
- Sustainability:
 - Renewable Energy
 - Energy Efficiency
 - Green Engineering
 - Sustainable Design
- Biomedical Engineering:
 - Medical Devices
 - Prosthetics
 - Biomechanics

Where to Find These Keywords:

- University Course Catalogs: Search for these terms in course descriptions.
- Faculty Research Profiles: Many professors conduct research related to these areas.
- Engineering Education Journals: Look for articles in journals like:
 - *Journal of Engineering Education*
 - *IEEE Transactions on Education*
 - *International Journal of Engineering Education*

By systematically searching for these keywords, you can gain a comprehensive understanding of how entrepreneurship is integrated into mechanical engineering curricula at different institutions.

Disclaimer: This list provides a strong foundation, but the specific keywords and their emphasis will vary across universities and programs.

Prompt: What motivates incorporation of entrepreneurship or entrepreneurial concepts in mechanical engineering curricula found in colleges and universities? Use peer reviewed academic sources when generating a response.

AI Output for Google. Gemini 1.5 Flash. Jan. 5, 2025. <https://gemini.google.com/>

1. Preparing Graduates for the Modern Workforce:

- Increased Demand for Entrepreneurial Skills:
 - The modern economy increasingly values innovation, problem-solving, and the ability to identify and capitalize on opportunities.
 - Graduates with entrepreneurial skills are better equipped to navigate dynamic career paths, adapt to change, and contribute to economic growth.
- Developing a Global Mindset:
 - Entrepreneurship education fosters a global perspective, encouraging students to consider societal needs and global challenges.
 - It prepares them to work in diverse and international environments.

2. Fostering Innovation and Creativity:

- Driving Technological Advancement:
 - By encouraging entrepreneurial thinking, engineering programs can cultivate a culture of innovation and drive the development of new technologies and solutions to pressing global challenges.
- Cultivating a Growth Mindset:
 - Entrepreneurship education helps students develop a growth mindset, emphasizing iterative learning, risk-taking, and resilience.
 - This fosters a deeper understanding of the design process and encourages continuous improvement.

3. Enhancing Learning and Engagement:

- Real-World Application:
 - Entrepreneurial projects provide students with opportunities to apply their theoretical knowledge to real-world challenges, making learning more engaging and relevant.
- Developing 21st-Century Skills:
 - Entrepreneurship education helps students develop critical thinking, communication, teamwork, and leadership skills – essential for success in any career.

4. Economic and Social Impact:

- Job Creation:
 - By encouraging students to become entrepreneurs, universities can contribute to job creation and economic growth.
 - Student startups can create new businesses and drive innovation in various sectors.
- Addressing Societal Challenges:
 - Entrepreneurial projects often focus on addressing societal challenges, such as climate change, poverty, and healthcare.
 - This allows students to use their engineering skills to create positive social and environmental impact.

Peer-Reviewed Sources:

- Articles in academic journals like:
 - *Journal of Engineering Education*
 - *IEEE Transactions on Education*
 - *International Journal of Engineering Education*

Note: These motivations are interconnected and mutually reinforcing. By integrating entrepreneurship into their curriculums, mechanical engineering departments can better prepare graduates for the challenges and opportunities of the 21st century.

This information is based on current research and may evolve as the needs of the global economy and the engineering profession continue to change.