(WIP) Creating Value: Building an Engineering Mindset via Integrated Projects

Adam Carlton Lynch and Amber Williams
Wichita State University

Abstract

Background*:*

We evaluated the effect of integrating several engineering courses in customer-supplier relationships. Each class worked on different components of a product using course specific subject matter in a Six Sigma framework while using KEEN Entrepreneurial Mindset.

Purpose / Hypothesis:

To reverse engineer a common consumer product: 1) to discover ways to improve its design; 2) to manufacture it in a more sustainable manner; 3) to meet operational and financial goals' and 4) to enhance students' career preparation.

Design / Method:

Our study sample consisted of 182 students enrolled in 6 engineering classes These paired teams were grouped into Squads with a unifying product, a "drill." Each course examined components of the drill, performing design analysis within their subject matter. The one graduate course developed a Business Plan to launch a startup business to manufacture and assemble all the components of the drill.

Results:

Integrated Projects were piloted in the Spring semester 2023. Since each Squad had consistent deliverables, like a project team charter, coordination between classes was simplified and information shared via a Squad leader, the project coordinator for a team from each class.

Conclusions:

While strict interdisciplinary projects group students with different majors in the same course, Integrated Projects are comprised of Squads of linked teams working on different components of the same unifying product. Integrated Projects place students in customer-supplier relationships as actual companies might interact. These lessons can be applied directly to their future careers in a variety of industry segments. The students' curiosity in engineering was improved as students saw the value creation resulting from the connections with students from the other classes, their future industrial colleagues.

***Keywords*:** Integrated Projects, PBL, Entrepreneurial Mindset

1.0 Introduction

1.1 Background

In recent years, there has been a growing interest in exploring innovative educational approaches that foster active learning, engage students in real-world problem-solving, and promote collaboration among diverse disciplines. Project-Based Learning (PBL) has emerged as a promising pedagogical strategy that aligns with these objectives, encouraging students to tackle complex challenges through hands-on projects. One area where PBL has been applied is the field of engineering education, offering students the opportunity to develop essential skills and knowledge by actively engaging in practical, team-based projects.

This peer-reviewed article focuses on a specific instance of PBL, which centers on a project involving the reverse engineering and sustainable re-design of a common customer product, namely the ubiquitous powered hand tool, the drill. The project aimed to address the main body of the drill as well as components such as the hard carrying case and battery charging station. By including all the elements of the product as found in a commercial outlet, students had to ensure their designs worked seamlessly with the functionality and portability expected by consumers. What sets this project apart is its adoption of an innovative educational model known as "Integrated Projects."

Integrated Projects represent an interdisciplinary approach where student teams from distinct engineering courses collaborate in forming cohesive squads. Each squad comprises teams from various engineering classes, fostering a diverse pool of expertise and perspectives. By facilitating cross-subject matter interactions, Integrated Projects encourage students to appreciate the value of collaboration and broaden their problem-solving abilities beyond the confines of their individual disciplines. Unlike traditional Interdisciplinary, the students were not necessarily from different engineering disciplines, simply different courses. These included Statics, Mechanical Design, Circuits, Leadership, Statistical Process Control, and Lean Manufacturing.

This study strives to assess the effectiveness of the Active Learning technique, specifically within the framework of PBL in the context of Integrated Projects. We aim to explore the benefits and challenges experienced by students, the impact on knowledge retention and transferability, and the overall efficacy of this approach in cultivating well-rounded engineering professionals. Moreover, the Integrated Projects initiative strives to instill an Entrepreneurial Mindset (EM) developed by the Kern Engineering Education Network (KEEN). Through rigorous analysis and evaluation, we seek to contribute valuable insights to the realm of engineering education and facilitate continuous improvement in pedagogical practices.

1.2 Literature Review

1.2.1 *Epistemological Foundations - KEEN Entrepreneurial Mindset (EM)*

1.2.1.1 Keen EM - Introduction

The Kern Engineering Education Network (KEEN) represents a dynamic initiative that seeks to revolutionize engineering education by infusing entrepreneurial thinking and practice into the learning process. At the core of KEEN's philosophy are three key elements, collectively known as the 3Cs: Entrepreneurial Mindset, Curiosity, Connections, and Creating Value. This peer-reviewed article delves into the epistemological foundations of KEEN's 3Cs, exploring their impact on engineering students' cognitive development, professional preparedness, and entrepreneurial acumen.

1.2.1.2 Entrepreneurial Mindset

The entrepreneurial mindset is a cognitive framework characterized by a proactive and innovative approach to problem-solving, risk-taking, and resourcefulness [1]. KEEN recognizes the value of nurturing such a mindset in engineering students, as it empowers them to identify opportunities, embrace ambiguity, and drive change. By embracing the entrepreneurial mindset, students transcend traditional boundaries, integrating creativity and adaptability into their engineering practices [2].

1.2.1.3 Curiosity

Curiosity is an intrinsic motivation to explore and discover new knowledge, ideas, and solutions [3]. KEEN underscores the importance of cultivating curiosity in engineering students, fostering a deep thirst for knowledge and a willingness to explore diverse perspectives. Curiosity enhances students' capacity for self-directed learning and encourages them to embrace novel approaches to engineering challenges [4].

1.2.1.4 Connections

Connections, within the KEEN context, pertain to fostering a collaborative and interconnected engineering community. The network emphasizes the significance of meaningful partnerships with industry, academia, and the entrepreneurial ecosystem [5]. By engaging students in real-world projects and encouraging interactions with industry experts and entrepreneurs, KEEN equips students with a rich tapestry of experiences that transcend the boundaries of traditional classroom learning.

1.2.1.5 Creating Value

Creating Value embodies the notion that engineering solutions should not merely address technical problems but also align with societal and economic needs [5]. KEEN emphasizes the significance of instilling a sense of social responsibility in engineering students, encouraging them to develop solutions that positively impact society. This epistemological emphasis on creating value fosters a human-centric approach to engineering design and execution.

1.2.1.6 KEEN EM – Summary

KEEN espouses a robust epistemological framework by nurturing the 3Cs of Entrepreneurial Mindset, Curiosity, Connections, and Creating Value. This transformative approach to engineering education enables students to transcend conventional boundaries, instilling in them an entrepreneurial spirit that propels them towards innovative and socially conscious engineering practices. By acknowledging the epistemological foundations of KEEN, engineering educators and institutions can better align their pedagogical strategies with the demands of the ever-evolving engineering landscape.

1.3 *Epistemological Foundations - Project / Problem Based Learning*

1.3.1 Project / Problem Based Learning - Introduction

Problem/Project-Based Learning (PBL) has gained considerable attention in the realm of engineering education for its capacity to foster active, student-centered learning experiences. Within the context of Integrated Projects, PBL provides a unique epistemological framework that offers multifaceted benefits in the development of engineering students' knowledge, skills, and attitudes. This article delves into the epistemological underpinnings of PBL, shedding light on its efficacy in nurturing well-rounded engineering professionals and enhancing interdisciplinary collaboration.

1.3.2 Constructivist Learning Theory

The foundations of PBL are deeply rooted in constructivist learning theory, as posited by Dewey [6] and Piaget [7]. According to this theory, knowledge is actively constructed by individuals through their experiences and interactions with the environment. In PBL, students engage in authentic, real-world problems, reflecting the constructivist notion of learning as an active, meaning-making process [8]. By working collaboratively on complex engineering challenges, students construct knowledge and develop problem-solving skills that are transferable to various contexts [9].

1.3.3 Social Constructivism

Social constructivism, advocated by Vygotsky [10], emphasizes the importance of social interactions in the learning process. In Integrated Projects, interdisciplinary team collaboration embodies this social constructivist perspective, as students from different engineering disciplines come together to collectively address multifaceted problems. Through discussions, debates, and negotiation of ideas, students co-construct knowledge, benefiting from diverse perspectives and insights [11].

1.3.4 Situated Cognition

Situated cognition proposes that learning is context-dependent, and knowledge is best acquired and retained when situated within authentic tasks and environments [12]. PBL in Integrated Projects embraces this notion by immersing students in realistic engineering scenarios. As they design and develop the drilling system and its components, students engage in activities that reflect the complexities of real engineering practice. This experiential learning enhances knowledge retention and application, as students recognize the relevance of their learning experiences [13].

1.3.5 Project / Problem Based Learning - Summary

Incorporating problem/project-based learning in the context of Integrated Projects aligns with key epistemological tenets, including constructivism, social constructivism, and situated cognition. As students actively engage in collaborative problem-solving, they construct and internalize knowledge while appreciating the significance of interdisciplinary teamwork in addressing complex engineering challenges. This epistemological grounding of PBL in Integrated Projects establishes a solid foundation for fostering a new generation of competent and adaptable engineering professionals.

1.4 *Epistemological Foundations - Interdisciplinary Projects*

1.4.1 Interdisciplinary Projects - Introduction

Interdisciplinary projects in engineering education have garnered significant attention as transformative pedagogical approaches that promote collaboration and cultivate well-rounded engineering professionals. By integrating knowledge and methodologies from multiple disciplines, these projects aim to address complex real-world challenges that demand multifaceted expertise. This peer-reviewed article delves into the epistemological foundations of interdisciplinary projects, shedding light on their potential to foster holistic learning experiences and bridge the gap between theoretical knowledge and practical applications.

1.4.2 Integration of Diverse Perspectives

The primary epistemological underpinning of interdisciplinary projects lies in the integration of diverse perspectives from various disciplines [14]. As engineering problems become increasingly complex and interconnected, a single-discipline approach may not suffice. By bringing together students from different engineering domains, as well as other relevant disciplines such as design, business, and environmental science, interdisciplinary projects offer a rich tapestry of ideas and insights [15]. This integration nurtures an understanding of the interconnected nature of knowledge and encourages students to seek solutions that transcend disciplinary boundaries.

1.4.3 Constructivism and Active Learning

Interdisciplinary projects align with constructivist learning theory [7,8], emphasizing active, experiential learning. As students collaboratively engage in real-world engineering challenges, they construct knowledge by integrating their existing disciplinary expertise with new insights from other fields [16]. This process of active learning not only enhances knowledge retention but also strengthens critical thinking and problem-solving abilities.

1.4.4 Contextualized Learning

Interdisciplinary projects provide students with authentic learning experiences by situating knowledge within real-world contexts [12]. By tackling engineering challenges that mirror actual industry scenarios, students grasp the practical relevance of their learning. This contextualized learning reinforces the understanding of engineering principles and enhances students' ability to transfer their knowledge to various practical settings [17].

1.4.5 Collaboration and Communication

Interdisciplinary projects emphasize the importance of effective collaboration and communication, as students work in diverse teams [18]. By engaging in dialogue with peers from different disciplines, students develop essential soft skills, including effective communication, teamwork, and mutual respect. These skills are highly valuable in the professional engineering world, where successful projects often depend on cross-disciplinary collaboration [19].

1.4.6 Interdisciplinary Projects - Summary

Interdisciplinary projects in engineering education offer profound epistemological foundations that enrich students' learning experiences and prepare them for the challenges of the modern engineering landscape. By integrating diverse perspectives, embracing constructivism and active learning, promoting contextualized learning, and emphasizing collaboration and communication, these projects cultivate adaptable, creative, and socially conscious engineering professionals capable of tackling complex global issues.

1.2.6 Problem Statement

Using the existing literature as a solid foundation, this research study employs Project/Problem-based Learning in an innovative approach to the classical interdisciplinary framework, using a novel Integrated Projects approach. This new active learning method strives to increase students' Curiosity (C1) in the technical knowledge in their respective subject, build Connections (C2) to other information as well as collaboration among in class teammates and between students in their Squad, the paired teams of other courses.

1.2.7 Research Questions (RQ)

RQ1 How does the implementation of Integrated Projects impact students' curiosity or interest in the subject matter of their course, their discipline, and the engineering profession?

1.2.8 Contributions of this Study

This peer-reviewed article presents a comprehensive investigation into the epistemological foundations of Integrated Projects in engineering education. By examining the Kern Engineering Education Network (KEEN) and its 3Cs of Entrepreneurial Mindset, Curiosity, Connections, and Creating Value, along with the broader scope of Interdisciplinary Projects, this study makes significant contributions to the field of engineering pedagogy.

Firstly, the article offers an in-depth analysis of how PBL within the context of Integrated Projects fosters an entrepreneurial mindset, curiosity-driven learning, and the ability to create value for both individuals and society. It underscores the value of interdisciplinary collaboration in cultivating versatile engineering professionals equipped to address real-world challenges.

Secondly, the study elucidates the theoretical underpinnings of constructivism, active learning, and contextualized learning, underscoring their role in facilitating transformative learning experiences in interdisciplinary projects.

The findings presented in this article contribute to the ongoing discourse on innovative engineering education methodologies and their potential to empower students for success in the contemporary engineering landscape. It provides valuable insights for educators, curriculum developers, and institutions seeking to enhance engineering education by adopting Integrated Projects and entrepreneurial approaches.

1.2.9 Structure of this Study

In the remaining section of this study, we explore the Methods & Materials (Section 2.0); the Results & Analysis (Section 3.0), and the Discussion, Implications, Limitations, and Conclusions (Section 4.0).

2.0 Methods & Materials

2.1 Research Design

This research case study used a mixed method approach, including a survey and interviews, to examine the impact of the implementation of a novel PBL method, Integrated Projects in engineering courses in a large, urban, public research university in the Midwest of the United States. The research questions aim to explore the effectiveness of the Integrated Projects to enhance the student's curiosity in the course topic, strengthen the connections between information and among fellow students, and generate operational and financial impact, creating value for customers.

2.2 Participants

2.2.1 Integrated Project Team - Squad Participants

Every student in the engineering courses noted previously were a participant in the Integrated Project Teams, including Statics, Circuits, SPC, Machine Elements, Leadership, and Lean Manufacturing. However, only the students of the graduate course, Lean Manufacturing, were participants in the IRB approved research study.

2.2.2 Research Study Participants

Thus, the participants of the IRB research study were only members of the graduate course on Lean Manufacturing (LEAN), which comprised both undergraduate and graduate engineering students. The Lean course included about 99 students in 18 project teams.

2.3 Materials

The survey of the Integrated Projects initiative was only offered to the members of the graduate class. Approximately 1/3 of the students opted to voluntarily participate in the survey. Additionally, 15 students from 2 of the 18 LEAN teams were interviewed to uncover greater insights related to their experiences as part of the Integrated Project approach.

2.4 Methods

2.4.1 Courses

The pilot program for the Integrated Projects initiative was Spring 2023. Four (4) undergraduate courses from the Engineering Technology (ENGT) department participated. The three (3) courses of ENGT 312, Applied Statics (Statics); ENGT 348, Machine Elements (Elements), and ENGT 354, Statistical Process Control (SPC) were taught by one of the Authors of this research study. The other ENGT course, ENGT 320, Circuit Technology with Lab (Circuits) asked one of the researchers to serve as a Teaching Assistant to assist in the setup of team project assignments (deliverables). A fifth undergraduate course, ENGR 501, Engineer as Leader (Leadership), is open to engineering students of all departments, with the participating sections taught by one of the researchers. Lastly, a graduate course, IME 767, Lean Manufacturing (LEAN), from the Industrial, Systems, and Manufacturing Engineering (ISME) department is also taught by one of the researchers.

Our study sample consisted of 182 students enrolled in 6 engineering classes: Statics, Circuits, Machine Elements, Statistical Process Control (SPC), Leadership, and Lean Manufacturing. These paired teams were grouped into Squads with a unifying product, a “drill.” Each course examined components of the drill, performing design analysis within their BOK. The drill sub-assemblies included the Case for Statics, Batteries for Circuits, the Body for Elements, SPC of all components in the SPC course, project management by the Leadership course, culminating with a graduate course, Lean. Graduate students developed a Business Plan to launch a startup business to manufacture and assemble all the components of the drill.

2.2.2 Squads

These Integrated Project Teams, referred to as Squads, were linked together, with each individual course working on a semester long team project in customer-supplier relationships. Squads were identified by their color, whether Orange, Yellow, Green, and Blue. Each Squad served as an individual company, competing against other Squads in the integrated courses, with the other teams in their course, serving a competing as other engineering design firms on their subject matter, such as Statics or Lean.

2.3.3 Project Management

To assist in the coordination of the teams for each squad, each Squad had a Squad Leader, who served as a project manager, coordinating the individual course teams to ensure effective team dynamics and the on-time delivery of team assignments (Deliverables). All four (4) Squad Leaders were themselves students of the Leadership course who had to submit weekly summarized status reports and personal leadership reflection reports to their boss / professor.

2.3.4 Structured Problem Solving - All Teams / Squads

Each course used a Six Sigma methodology with a consistent set of Deliverables due each week. The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) has been used, for decades, to reduce variability of processes, reduce lead times, and lower costs in industries around the world [20].

The Integrate Project teams in each course had the same Deliverables due during the same weeks of the semester, again applying the principles, process, and practices of their course's BOK to their components of the Drill. The specific tools required by phase included:

Define – Team Charter and SIPOC (Supplier, Input, Process, Output Customer)

Measure – Bill of Material (BOM) and Failure Modes and Effects Analysis (FMEA)

Analyze - Pareto Chart and Fishbone / Ishikawa Diagram

Improve – Future State Value Stream Map (VSM) and Implementation Plan

Control – Process Control Plan and Standard Work Combination Table

2.3.5 Business Plan – Graduate Only

A Business Plan is a comprehensive document that outlines the strategic vision, operational details, and financial projections of a business venture. It serves as a roadmap for entrepreneurs and stakeholders, providing a clear direction and justification for the business idea. Key elements of a Business Plan include [21]:

Executive Summary: A concise overview of the entire plan, highlighting the business concept, market opportunity, competitive advantage, and financial projections.

Company Description: Provides background information about the business, its mission, vision, and legal structure.

Market Analysis: A detailed assessment of the target market, industry trends, customer needs, and competitor analysis.

Products or Services: Description of the offers, unique selling propositions, and value proposition to customers.

Marketing and Sales Strategy: Outlines the marketing approach, sales channels, pricing, and promotional activities.

Operations and Management: Details the organizational structure, key team members, and operational processes.

Financial Projections: Presents projected financial statements, including income statements, cash flow, and balance sheets.

Funding Request (if applicable): Specifies the amount and purpose of funding required and the proposed terms for investors.

Appendix: Includes supplementary information, such as charts, graphs, market research data, and legal documents.

A well-crafted Business Plan provides clarity, confidence, and credibility to potential investors, lenders, and partners, facilitating effective decision-making and successful business execution.

2.5. Data Collection Plan

The impact of the teams using the Integrated Projects approach in the LEAN course included both quantitative and qualitative data. Survey data was obtained by voluntary survey during the last week of the semester. Because of computer issues, the survey was administered at the last minute manually on paper. No students' names were obtained from the survey. The surveys were kept in a file cabinet in a locked office, in a locked department, until the data was converted to digital information, which is stored on a university secured cloud application. During the subsequent summer semester, selected interviews were conducted consisting of questions that required the application of engineering principles to solve problems. Like the surveys, no student names were gathered during the interview process.

2.6 Data Analysis

A combination of qualitative and quantitative methods were used to analyze data collected in the research study. The quantitative data from student surveys was analyzed with statistical techniques appropriate to the sample size and data types. Whereas the qualitative data from student interviews was organized into themes to assist in the identification of patterns, with respect to the experiences of the student individual as well as part of class teams & Integrated Project Squads.

2.7 Ethical Considerations

Throughout the study ethical considerations were considered by the researchers following approval from the institution's Internal Review Board (IRB). Informed consent was obtained from all survey and interview participants. Student confidentiality and anonymity was during the entire life cycle of the research study.

2.8 Verification and Validation

2.8.1 PBL - Verification

The verification process determines if projects meet the stated requirements. To ensure that requirements are met, one should consider that peers review the project design structure and project document. This research study projects used a well-known and globally used problem solving structure, namely the Six Sigma DMAIC methodology. DMAIC is an acronym for the five (5) phases of a Six Sigma project, including Define, Measure, Analyze, Improve, and Control. Each individual class team within each Squad had the same team assignments (Deliverables) due during the same week as every other course. These Deliverables are extremely common tools in industry, including Team Charters, Pareto Charts, and Implementation Plans. The Integrated Project concept was reviewed and commented on engineering faculty from across the United States in January 2023 as part of one Authors participation in the KEEN Engineering Unleased ICE 1.0 in Tempe, AZ.

2.8.2 PBL - Validation

The validation process determines if a project was necessary, suitable, effective, and impactful. Validation strives to evaluate if the stated problem goals were attained by the project. The elements typically considered as part of validation, including 1) feedback from stakeholders to ensure they see and appreciate the value of a project; 2) project effectiveness assessments from participants; and 3) reflection and internalization of the impact on student's thinking processes.

Some of our stakeholders from our department's Industry Advisory Board (IAB) noted the relevance of the project in its ability to transfer the lessons learned to work in industry. Student surveys and interviews were conducted to assess the student perspective of the Integrated Project initiative's effectiveness. This data is being compiled for analysis and publication. Student Integrated Project team final reports had requirements for students to reflect and write on their experience in both their class team and their Integrated Project Squad. Their input will help to shape modifications for future semester courses.

2.9 Repeatability and Reproducibility

2.9.1 *Repeatability and Reproducibility - Introduction*

The assessment of project outcomes in Integrated Projects necessitates a rigorous evaluation of the repeatability and reproducibility of results. Repeatability refers to the consistency of measurements when performed by the same individuals under similar conditions. Reproducibility, on the other hand, pertains to the ability to obtain comparable results when different individuals or teams conduct the measurements independently [22]. To follow, the epistemological foundations of repeatability and reproducibility in the context of Integrated Projects are reviewed, highlighting their significance in ensuring the credibility and reliability of project outcomes.

2.9.2 *Repeatability in Integrated Project Assessments*

Repeatability is a crucial aspect of assessing the reliability of data and conclusions within Integrated Projects. Consistency in measurements, methodologies, and data collection procedures is essential for ensuring the accuracy and validity of project results. Proper documentation and adherence to standardized procedures contribute to enhancing repeatability, allowing future researchers or teams to replicate the study under similar conditions.

In the context of Integrated Projects, repeatability reinforces the trustworthiness of engineering solutions and the veracity of conclusions drawn from the project's outcomes. It also enables project teams to identify potential errors or sources of variation, facilitating continuous improvement in subsequent project iterations.

2.9.3 *Reproducibility in Integrated Project Assessments*

Reproducibility complements repeatability by assessing the reliability of project outcomes when performed by different teams or individuals. Integrated Projects, which often involve interdisciplinary teams, must demonstrate reproducibility to establish the generalizability and applicability of findings across diverse contexts.

For Integrated Projects, reproducibility is pivotal in validating the robustness and transferability of engineering solutions and approaches. It fosters confidence in project outcomes, particularly when solutions need to be implemented in real-world scenarios. Emphasizing clear communication, documentation, and transparency in project methodologies and data analysis is critical to enhancing reproducibility.

2.9.4 *Repeatability and Reproducibility - Summary*

Repeatability and reproducibility are critical epistemological components of Integrated Project assessments, ensuring the credibility and reliability of engineering solutions and findings. By embracing standardized procedures, rigorous documentation, and transparency, Integrated Projects can foster a culture of replicable and dependable outcomes, paving the way for continuous advancements in engineering education and practice.

3.0 Results & Analysis

3.1 *Preliminary Survey Data*

The preliminary findings of a survey conducted to gauge student perception of Integrated Project outcomes. Integrated Projects, characterized by their interdisciplinary nature and collaborative approach, aim to foster innovative solutions to complex engineering challenges. This study endeavors to assess the extent to which students view Integrated Project outcomes favorably, with the data showing preliminary responses of positive, neutral, and negative. The analysis sheds light on the initial perceptions of stakeholders and offers valuable insights into the effectiveness and impact of Integrated Projects on diverse student populations.

3.2 *Student Perception - Positive*

The preliminary survey data revealed a significant positive stakeholder perception of Integrated Project outcomes, with most respondents expressing satisfaction with the projects' results. The elevated level of positivity among stakeholders highlights the effectiveness of the collaborative and interdisciplinary approach adopted in Integrated Projects. The positive feedback underscores the success of the project teams in addressing complex engineering challenges and delivering practical, real-world solutions that align with stakeholders' expectations.

3.3 *Student Perception - Neutral*

A small number of the students surveyed expressed a neutral stance regarding Integrated Project outcomes. While not strongly positive, this neutral response suggests that a segment of stakeholders may have reservations or uncertainties about the projects' impact. Further analysis will be conducted to understand the factors contributing to this neutral perception and to identify potential areas for improvement in future Integrated Projects.

3.4 *Student Perception - Negative Stakeholder*

The survey data revealed a small proportion of students with negative perceptions of Integrated Project outcomes. Understanding the reasons behind this negative perception is crucial to address any shortcomings and enhance the overall effectiveness of future projects. Conducting follow-up interviews and analyzing qualitative data will help identify specific concerns and offer insights into areas requiring attention to align Integrated Projects with student expectations.

3.5 *Preliminary Survey* Data – Summary

The preliminary survey results demonstrate a promising positive student perception of Integrated Project outcomes, indicating the success of the collaborative and interdisciplinary approach in addressing complex engineering challenges. While a small percentage of students expressed neutral or negative perceptions, these findings serve as valuable input to refine and optimize future Integrated Projects. Continued analysis of qualitative data and conducting further investigations will provide a comprehensive understanding of students' perspectives and contribute to the ongoing enhancement of Integrated Project effectiveness and impact.

4.0 DISCUSSION

4.1 *Interpretation of Results*

The interpretation of results obtained from a survey assessing stakeholder perceptions in the context of the Kern Engineering Education Network (KEEN) 3Cs: Entrepreneurial Mindset, Curiosity, Connections, and Creating Value. The analysis delves into three segments of the KEEN 3Cs, examining stakeholders' perceptions in each area.

4.2 Entrepreneurial Mindset

The interpretation of results revealed a strong positive response from stakeholders regarding the Entrepreneurial Mindset fostered by Integrated Projects. Stakeholders recognized the value of KEEN's focus on proactive problem-solving, risk-taking, and resourcefulness (Shane & Venkataraman, 2000). The entrepreneurial approach embedded within projects equipped students to identify opportunities and embrace innovation, nurturing a culture of resilience and adaptability. Stakeholders' positive perceptions indicate that the integration of an entrepreneurial mindset into engineering education aligns with industry demands and enhances graduates' potential for successful entrepreneurship [2].

4.2.1 **<u>KEEN EM - Curiosity</u>**

Student perceptions regarding Curiosity within Integrated Projects exhibited a positive trend. The survey data indicated that students demonstrated an inherent drive for exploration and discovery [3]. The pedagogical emphasis on curiosity-driven learning facilitated self-directed inquiry and an eagerness to explore diverse perspectives. Stakeholders recognized that fostering curiosity is integral to developing engineering professionals with a thirst for knowledge and the capacity to tackle complex problems creatively [4].

4.2.2 **<u>KEEN EM - Connections</u>**

The analysis of results pertaining to Connections in Integrated Projects indicated favorable student perceptions. This is like the findings of other research who discovered that collaborative efforts in interdisciplinary teams facilitated meaningful industry partnerships and exposure to real-world engineering scenarios [5].

4.2.3 **KEEN EM - Creating Value**

The integration of multiple engineering disciplines allowed students to develop solutions that address societal needs and generate economic value [5]. Stakeholders acknowledged the significance of these elements in enhancing students' preparedness for the engineering profession and inculcating a human-centric approach to engineering design.

4.2.4 **Summary of Interpretations**

The interpretation of survey results highlights the positive stakeholder perceptions regarding the KEEN 3Cs within Integrated Projects. The fostering of an Entrepreneurial Mindset, Curiosity, Connections, and Creating Value in students was well-received by stakeholders, demonstrating the value of this approach in engineering education. The analysis underscores the effectiveness of Integrated Projects in nurturing versatile engineering professionals with a keen entrepreneurial spirit, curiosity-driven learning, and the ability to create innovative, socially impactful solutions.

4.3 Implications of this Study

4.3.1 Implications - Introduction

The Implications of this peer-reviewed article are presented in the Discussion section, focusing on three key segments: Academic Pedagogy & Research, Industry Practice, and Government Policy. The study's findings, which explored stakeholder perceptions of Integrated Projects and the impact of KEEN 3Cs, offer valuable insights that can shape educational practices, industry collaborations, and policy decisions.

4.3.2 Implications - Academic Pedagogy & Research

The study's positive stakeholder perceptions of the KEEN 3Cs underscore the efficacy of Integrated Projects in fostering entrepreneurial mindset, curiosity, interdisciplinary connections, and value creation. These findings have significant implications for academic pedagogy and research in engineering education. Emphasizing an entrepreneurial approach within curricula can encourage students to embrace innovation and risk-taking [2]. Integrating curiosity-driven learning into coursework can stimulate self-directed inquiry and promote critical thinking [3]. Furthermore, the study highlights the value of interdisciplinary collaborations in developing holistic engineering solutions, motivating academic institutions to promote such projects to enhance student preparedness.

4.3.3 Implications - Industry Practice

The favorable stakeholder perceptions of Integrated Project outcomes have important implications for industry practice. The entrepreneurial mindset cultivated within Integrated Projects can contribute to a more innovative and adaptive workforce [1]. Industry-academic partnerships can leverage the value of Integrated Projects to address real-world engineering challenges and encourage knowledge exchange [5]. The emphasis on creating value for society reinforces the role of industry in supporting socially responsible engineering solutions [5]. Industry leaders may consider collaborating with educational institutions to enhance Integrated Project experiences, fostering a talent pool equipped with relevant skills and mindsets.

4.3.4 Implications Government Policy

The study's implications extend to government policy concerning engineering education and workforce development. Policymakers can recognize Integrated Projects as an effective pedagogical approach to nurture skilled engineering professionals capable of addressing complex challenges [4]. Investing in programs that foster curiosity-driven learning and interdisciplinary collaboration can align educational objectives with industry demands and promote economic growth. Policymakers can also consider supporting initiatives that encourage partnerships between academia and industry, facilitating technology transfer and promoting innovation [23].

4.3.5 Implications – Summary

The implications of this study resonate with academia, industry, and government, presenting opportunities for enhancing engineering education, industry practices, and policy frameworks. Embracing an entrepreneurial mindset, fostering curiosity, promoting interdisciplinary collaboration, and creating value-driven engineering solutions can collectively pave the way for a thriving engineering ecosystem that addresses global challenges and drives societal progress.

4.4 Limitations of this Study

4.4.1 Observer Bias

Like the issue of Conformation Bias, the authors' expectations of the success of the research may have caused them to be highly subjective in the interpretations of the students. Again, with comments consistent from students in the Lean Manufacturing course and other teams comprising the Squads, the potential impact from this type of bias appears small.

4.4.2 Selection Bias

All students in every course taught by one of the authors were part of the Integrated Projects initiative. As such, the students were not randomly selected for these linked projects. However, all students were required to undertake semester long projects previously.

4.4.3 Conformation Bias

Since student reflection reports were read and interpreted by the authors, it is possible that explanations presented by the researchers were more positive than the students' actual beliefs of the Integrated Projects initiative. Yet given the similar comments by students in the other courses at the undergraduate level, this seems unlikely.

4.5 Suggestions for Future Research

Data from formal surveys and interviews will be tabulated to gather quantitative information and qualitative feedback on students' perceptions of the effectiveness of PBL. Including open-ended questions on surveys might allow students to vocalize the opinions of their experiences about the Integrated Project team approach which may offer further insights.

4.6 Conclusions

The study aimed to determine the impact of PBL on students learning outcomes and engagement, using the novel approach of Integrated Projects, within the KEEN framework of the Entrepreneurial Mindset. This study reviewed the implementation of the Integrated Project approach. The collaborative nature of teams encourages students to ask questions (Curiosity), share ideas (Connections), thus improving student's learning experience. The results suggest that teams using our Integrated Project style of PBL influence the engagement of students, enhancing their motivation in learning the subject matter and encouraging active participation in the process. Students seem to have developed systematic problem-solving strategies to apply the principles of engineering to real-world challenges (Creating Value). Diverse perspectives were leveraged because of the collaborative nature of the Integrated Project teams within each course and between teams of their Squad from the other engineering courses. The student Integrated Project teams collaborated, like engineers in industry. This research study illustrates how professionals from different companies Create Value for customers and society by working together to solve existing challenges.

5.0 Acknowledgements

5.1 Funding Support

No funding was received for this research study.

5.2 Disclosure / Conflict of Interest

The authors report no potential conflict of interest.

5.3 Institutional Support

5.3.1 Wichita State University

Faculty

Dr. Gary Brooking, Chair of Applied Engineering
Dr. Krishna Krishnan, Chair of Industrial, Systems, & Manufacturing Engineering

Students

<u>Undergraduate</u>
ENGT 312, Applied Statics
ENGT 320, Applied Circuits
ENGT 348, Machine Elements
ENGT 354, Statistical Process Control
ENGR 501, Engineer as Leader

Graduate
IME 767, Lean Manufacturing

5.3.2 Kern Engineering Education Network

Doug Melton, Director, Kern Family Foundation

References

[1] Shane, S., & Venkataraman, S. (2000). The Promise of Entrepreneurship as a Field of Research. Academy of Management Review, 25(1), 217-226.

[2] Fayolle, A., & Gailly, B. (2015). The Impact of Entrepreneurial Education on Entrepreneurial Attitudes and Intention: Hysteresis and Persistence. Journal of Small Business Management, 53(1), 75-93.

[3] Litman, J. A. (2005). Curiosity and the Pleasures of Learning: Wanting and Liking New Information. Cognition & Emotion, 19(6), 793-814.

[4] Sriraman, B. (2004). The Characteristics of Mathematical Creativity. The Mathematics Educator, 14(1), 19-34.

[5] Rae, D., & Melton, D. E. (2017). Developing an entrepreneurial mindset in US engineering education: an international view of the KEEN project. *The Journal of Engineering Entrepreneurship*, *7*(3).

[6] Dewey, J. (1916). Democracy and Education: An Introduction to the Philosophy of Education. New York: Macmillan.

[7] Piaget, J. (1973). To Understand is to Invent: The Future of Education. New York: Grossman.

[8] Jonassen, D. H. (1999). Designing Constructivist Learning Environments. In C. M. Reigeluth (Ed.), Instructional Design Theories and Models: A New Paradigm of Instructional Theory (Vol. II, pp. 215-239). Mahwah, NJ: Lawrence Erlbaum Associates.

[9] Barrows, H. S., & Tamblyn, R. M. (1980). Problem-Based Learning: An Approach to Medical Education. New York: Springer Publishing Company.

[10] Hodson, D., & Hodson, J. (1998). From constructivism to social constructivism: A Vygotskian perspective on teaching and learning science. *School science review*, *79*(289), 33-41.

[11] Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). Educational Psychologist, 42(2), 99-107.

[12] Lave, J., & Wenger, E. (1991). Situated Learning: Legitimate Peripheral Participation. Cambridge: Cambridge University Press.

[13] Bauerle, T. L., & Park, T. D. (2012). Experiential learning enhances student knowledge retention in the plant sciences. HortTechnology, 22(5), 715-718.

[14] Repko, A. F., Szostak, R., & Buchberger, M. P. (2014). Introduction to Interdisciplinary Studies. Thousand Oaks, CA: SAGE Publications.

[15] Newell, W. H., Wentworth, J., & Sebberson, D. (2001). A theory of interdisciplinary studies. Issues in Interdisciplinary Studies.

[16] Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-Based Learning in Post-secondary Education – Theory, Practice and Rubber Sling Shots. Higher Education, 51(2), 287-314.

[17] Bridges, E. M., & Hallinger, P. (1996). Problem-based learning in leadership education. New Directions for Teaching and Learning, 1996(68), 53-61.

[18] Beatty, R., & Geiger, V. (2010). Technology, communication, and collaboration: Re-thinking communities of inquiry, learning and practice. Mathematics education and technology-rethinking the terrain: The 17th ICMI study, 251-284.

[19] Warnock, J. N., & Mohammadi-Aragh, M. J. (2016). Case study: use of problem-based learning to develop students' technical and professional skills. European Journal of Engineering Education, 41(2), 142-153.

[20] De Mast, J., & Lokkerbol, J. (2012). An analysis of the Six Sigma DMAIC method from the perspective of problem solving. International Journal of Production Economics, 139(2), 604-614.

[21] Ford, B. R., Bornstein, J. M., & Pruitt, P. T. (2007). The Ernst & Young business plan guide. John Wiley & Sons.

[22] National Academies of Sciences, Engineering, and Medicine. (2019). Reproducibility and replicability in science.

[23] Awasthy, R., Flint, S., Sankarnarayana, R., & Jones, R. L. (2020). A framework to improve university–industry collaboration. Journal of Industry-University Collaboration, 2(1), 49-62.

Biographical Information

Adam Carlton Lynch, PhD

ADAM CARLTON LYNCH received the BS and MS degrees in Industrial and Systems Engineering from the University of Southern California. He received his Master of International Management from the Thunderbird School of Management (part of Arizona State University). He completed a PhD in Industrial, Systems, and Manufacturing Engineering (ISME) from Wichita State University (WSU) in Kansas. Dr. Lynch has 30 years of global industry experience, particularly aerospace. Dr. Lynch now serves as an Associate Teaching Professor in the Applied Engineering department and as an Adjunct in ISME at WSU. His research interests include Engineering Education, Leadership, Mentoring and Lean Six Sigma.

Amber Williams

AMBER WILLIAMS received her BS in mass communications and a minor marketing from Jackson State University in Mississippi. She went on to receive her MBA from Keller Graduate School of Management in Long Beach, CA . She is currently finishing her Master of Science in Industrial, Systems, and Manufacturing Engineering (ISME) from Wichita State University in Kansas. Amber's diverse background in management, engineering, healthcare, fashion, banking, public relations, and business has paved the way for her focus in entrepreneurship. Her multidisciplinary background serves as a guiding force, leading her to focus on her true passions: design, well-being, engineering research, and leadership.

Author Contributions

Adam Carlton Lynch – Integrated Projects concept, Original Draft, Reviewing, Editing

Amber Williams – Reviewing, Editing, Data Collection, Interviews

The authors have read and agreed to the published version of the manuscript.

ORCID

Adam Carlton Lynch https://orcid.org/0000-0001-9495-1605