An Introductory Overview of Strategies used to Reduce Attrition in Engineering Programs

Dr. Niranjan Hemant Desai, Purdue University Northwest

Name: Dr Niranjan Desai
Qualifications: Ph.D Civil Engineering University of Louisville, USA
MES (Master of Engineering Studies) Civil Engineering University of Sydney, Australia
BTECH (Bachelor of Technology) Indian Institute of Technology, New Delhi, India.
Work Experience: Assistant Professor of Civil Engineering, Purdue University North Central (2013 - Present)
Graduate Research and Teaching Assistant, University of Louisville, (2006 - 2011) Tata Bluescope Steel Ltd Designation: Design Manager
Awards: Alan H. Yorkdale Memorial Award, 2014.

Dr. George Stefanek, Purdue University Northwest

Ph.D. Electrical Engineering, Illinois Institute of Technology
M.S. BioEngineering, University of Illinois at Chicago
B.S. Purdue University
An Introductory Overview of Strategies used to Reduce Attrition in Engineering Programs

Introduction

The United States requires qualified engineers for economic growth and prosperity. However, student retention is a challenge that faces engineering education. Reports from US universities show that student retention rates in engineering are in the range of 40-60% with attrition being a well-known issue1,2,3.

Studies concluded that inadequate teaching techniques and students’ lack of identification with their field of study also resulted in them discontinuing their degree program4. Additionally, students feel pressure when transitioning from a high school to a university environment which require them to independently manage their time, resources and to meet deadlines without the oversight from their parents1. It has been suggested that this stress is a factor that contributes to students’ decision to leave engineering programs. To deal with this problem, several first-year engineering programs provided academic and social support systems to assist students in coping with the challenging transition from high school to college. Despite these efforts, it has been observed that students transfer out of engineering programs due to a lack of interest in their chosen discipline1.

It has also been found that math and physics aptitude were predictors of academic success in college5. Students’ difficulty in succeeding in calculus courses were reasons that students transferred out of engineering programs.6,7,8 Despite the availability of tutoring services and review sessions on campus, the inability to succeed in math, specifically calculus, has been observed to be a consistent obstacle to student retention in engineering programs. This issue is not unique to only one institution, but is a ubiquitous problem6,7,8.

Krause et al.3 found that roughly 50% of students that departed from an engineering program prior to graduation, 85% of these students did so within the first two years while only 15% left after the first two years. Analysis showed that the probability of successfully graduating in engineering for those students entering with below calculus level skills was around 30%, while students who began their engineering experiences with adequate calculus-level skills had a 50% to 75% probability of graduating in their chosen major3.

Based upon the discussion above, student retention in engineering programs is an important issue that faces the engineering education community in the United States. This paper presents a general overview of the different techniques that have been used in universities primarily across the country to increase student retention in engineering programs. Since numerous attempts have been made to increase retention over the last few decades, this paper focuses only on more recent strategies that have been incorporated over the last five years (after year 2011) and concludes by recommending best practices for increasing student retention in engineering programs based upon an analysis of the reviewed literature.

Purpose of the Literature Review
The goal of this study is to present a brief description of strategies implemented over the last 5 years that reasonably represent the common themes that underlie the wide variety of diverse techniques that have been implemented to increase retention in engineering programs. The authors would like to emphasize that this is not a comprehensive literature review that encompasses all the different techniques that have been implemented to increase retention in engineering programs across the entire United States. This is an initial overview that will be expanded upon in the future. The authors would like to emphasize that the goal of this overview is not to critically compare the different techniques. Such an analysis lies outside the scope of this study and will be performed as a part of a follow-up investigation.

Research Methods

The review was conducted through a search of the ASEE.org website and google scholar. An emphasis has been placed on searching the ASEE website because conference papers are often not indexed in many databases. The key words used in the search included freshman engineering, retention in engineering, freshman bridge courses, and first year experience. An initial overview of the different retention techniques revealed that most of the techniques could be broadly classified as falling within some common themes. Some representative examples of retention approaches falling within these themes, or within an overlap of these themes are presented in this overview. The most commonly occurring themes underlying the implemented retention strategies that were encountered were:

1) Strategies focused on improving math, specifically calculus, and physics skills of incoming freshman.

2) Strategies focused on enhancing the sense of community and support, both academic and social, for incoming freshman students to create a strong identity among students as engineers, and to provide encouragement and support to underrepresented groups.

3) Strategies focused on improving the teaching techniques employed in engineering programs such as developing an active learning environment, increasing the use of technology in the classroom, and the use of peer mentors to better relate the challenges freshman students face in understanding classroom material.

4) Strategies focused on retaining student interest in their chosen discipline. These strategies include incorporating modules into freshman courses that involve the solving of practical engineering problems, and demonstrating the application of classroom concepts to real-world problems.

5) Strategies focused on incorporating more hands-on components into the classroom.

Table 1 presents all the retention techniques that have been summarized in this paper. The table comprises the reference number corresponding to the article in the “References” section, the article title, the theme within which the concerned retention strategy lies, and those articles that contained quantitative results. The relevant numbers from the articles that included quantitative results are presented in the discussion section.
<table>
<thead>
<tr>
<th>Ref #</th>
<th>Article Title</th>
<th>Type of Strategy</th>
<th>Articles with Quantitative Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>The Washington State Academic RedShirt (STARS) in Engineering Program.</td>
<td>Improving math skills, Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>A Comprehensive Plan with Emphasis on Math Preparation to Improve Retention and Graduation Rates in Engineering Fields.</td>
<td>Improving math skills, providing community-based support system, application of classroom concepts in industry</td>
<td>yes</td>
</tr>
<tr>
<td>11</td>
<td>Engineering Learning Communities: Relationships, Results, and Retention.</td>
<td>Improving math skills, Providing community-based support system, Application of classroom concepts in industry</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>How Important is the WOW Factor in First Year Engineering Courses?</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>The Wright State Model for Engineering Mathematics Education: A Longitudinal Study of Student Perception Data.</td>
<td>Improving math skills, Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Management and Assessment of a Successful Peer Mentor Program for Increasing Freshman Retention.</td>
<td>Mentorship program, Interaction with industry</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Building a Summer Bridge Program to Increase Retention and Academic Success for First-Year Engineering Students.</td>
<td>Improving math skills, Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>The Evolution of the Freshman Engineering Experience to Increase Active Learning, Retention, and Diversity--Work in Progress.</td>
<td>Introduction to campus resources, Introduction of hands-on work into classroom</td>
<td>yes</td>
</tr>
<tr>
<td>17</td>
<td>Assessing Knowledge and Application of the Design Process in a First-Year Engineering Design Course.</td>
<td>Application of classroom concepts in industry</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Engaging Freshman in Team Based Engineering Projects.</td>
<td>Application of classroom concepts in industry</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Summer Diversity Program enhances female and underrepresented minority student academic performance and retention in the Drexel University College of Engineering.</td>
<td>Improving math skills, Introduction of hands-on work into classroom, Providing community-based support system</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Project Title</td>
<td>Key Benefits</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Coherent Calculus Course Design: Creating Faculty Buy-in for Student Success.</td>
<td>Improving math skills, Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Integrated Physics and Math course for Engineering Students: A First Experience.</td>
<td>Improving math skills</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Enhancing Retention and Academic Success of Undergraduate Engineering Students.</td>
<td>Improving math skills</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Spatial Visualization Skills Intervention for First Year Engineering Students: Everyone's a Winner!</td>
<td>Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Spatial Thinking and STEM Education. When, Why, and How?</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Hands-on, discovery, critical thinking, and freshman engineering.</td>
<td>Introduction of hands-on work into classroom, Introduction of Technology into the classroom</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Improving Math Skills through Intensive Mentoring and Tutoring.</td>
<td>Improving math skills, Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Integrating Freshmen into Exploring the Multi-Faceted World of Engineering and Sustainability through Biofuels Synthesis from Waste Cooking Oil.</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Bringing technology to the First-Year Design Experience through the use of Electronic Design Notebooks.</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Assessing and Developing a First-year Introduction to Mechanical Engineering Course.</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Mathematics Performance and First Year Retention of Students in Engineering Learning Communities.</td>
<td>Improving math skills, Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Teaching Electronics to First-year Engineering Students.</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>The Paul Peck Program: A Multi-Year Leadership Development Program.</td>
<td>Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>RELATING TOY EVALUATION TO ENGINEERING FUNDAMENTALS IN A FRESHMAN ENGINEERING DESIGN COURSE.</td>
<td>Introduction of hands-on work into classroom</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Using Student Instruction to Increase Retention in Engineering.</td>
<td>Providing community-based support system</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>
Retention Techniques

As discussed in “Introduction” section, student attrition is a concern for engineering and technology programs and engineering colleges. Different strategies have been used in an attempt to increase retention in engineering programs that were based upon addressing the core issues believed to be responsible for decreasing retention rates as summarized in the introductory section. Generally, the approaches implemented involved assisting students in improving their mathematics and physics skills in a supportive, collaborative environment with the help of tutors, peers and faculty members outside regular classroom hours. Additionally, hands-on projects were used that involved the application of engineering concepts in the freshman year. Also, more collaborative, interactive and supportive learning environment were created in which students had more contact with their peers and instructors and thereby did not feel isolated. Finally, modern technological tools were introduced into the classroom to make the lectures more exciting and to keep pace with the increased influence of technology in students’ lives.

This section provides a review of a variety of specific techniques that have been implemented across engineering programs to increase retention. Key features of these innovative additions to engineering programs are presented below.

Improving math skills, Providing community-based support system: Kingma et. al. created a program “Academic Redshirt” (STARS) that helped retain economically and educationally disadvantaged students in engineering programs at the University of Washington and Washington State University. The program offered resources, a social community, and intensive support with a high touch approach to prepare students with the academic and learning skills required to be successful in their engineering studies. The academic focus of the STARS program was on bringing student math skills and efficacy up to levels required to successfully pass Calculus I, an early indicator of the future success in an engineering program.

Improving math skills, providing community-based support system, application of classroom concepts in industry: Shadaram et al. described the implementation of a comprehensive engineering education improvement plan at University of Texas, San Antonio which included a fusion of strategies with the objective of minimizing factors that adversely affect academic performance of entering minority freshmen in order to increase post-secondary enrollments, retention, and increase collaboration between the university’s engineering departments and private industry in Texas.

This bridge program focused on creating a “Just-In-Time” (JIT) pedagogical approach to non-calculus ready students and maintained and strengthened the engineering mentoring programs with the goal of increasing the number, retention, and graduation time and rates of minority engineering students. The plan included an integrated strategy that involved combining five education best practices of recruitment, formal mentoring through peer mentors, summer camp engineering math preparation and workshops, academic year stipends, and summer internships at local and regional companies.

The Just in Time Math (JITM) strategy was implemented to increase the interaction between freshmen and engineering faculty and peers during the first semesters of study. As a result, more
engineering students have shown greater enthusiasm for the field of engineering which resulted in better retention and graduation rates. The JITM course included lecture, lab and recitation components and an application-oriented, hands-on approach. The JITM course addressed math topics specifically used in the core entry-level engineering courses (traditional physics, engineering mechanics, electric circuits and computer programming courses). It replaced the traditional math prerequisite for the core courses, so that students can advance in the engineering curriculum without first completing the required calculus sequence. This shifted the traditional emphasis on math prerequisite requirements to an emphasis on engineering motivation for math with a "just-in-time" structuring of the new math sequence. The course content consisted of math prerequisites for Engineering Physics I, Statics, Network Theory, and Computer Programming with Engineering Applications. To further improve students’ readiness for more advanced engineering classes, the application of math to engineering topics was incorporated by adding physical measurements to the content of the Applied Engineering Analysis 1 course. The initial assessment indicated a substantial improvement in the retention rates among JITM students in comparison to traditional engineering students.

Improving math skills, Providing community-based support system, Application of classroom concepts in industry: Lockwood-Cooke et al.\textsuperscript{11} described the creation of engineering learning communities at West Texas A&M University that dual enrolled first-year engineering students into a section of Fundamentals of Engineering and a freshman level mathematics course, either pre-calculus or Calculus I. The program was expanded to offer a learning community that linked Calculus II and Engineering Statics. The engineering learning community model integrated mathematics and engineering, and additionally through Problem-Based Learning (PBL) provided real world application experiences for students. The goal of the program was to increase retention of first year engineering majors by creating a community of learners that would form study groups early in their academic career, and use PBL to integrate mathematics and physics into practical engineering applications that increase student engagement.

Two learning communities linked the courses of Fundamentals of Engineering with two freshman mathematics courses pre-calculus and Calculus I. The key elements of the Engineering Learning Community model were: 1) the emphasis of the goals of the learning community throughout the semester, 2) consistent integration of the mathematics and engineering course curriculum throughout the semester, and 3) implementation of PBL projects into the courses describe above which allowed students to apply theoretical engineering and mathematics principles to the solution of engineering problems.

The mathematics faculty felt the key to the success of the program was to integrate engineering applications into the pre-calculus and calculus curriculum. When possible, a new mathematics concept was introduced into the context of an engineering application. The introduction of a new topic was also used as the startup of a PBL project. By introducing the project before the content was covered, students could hypothesize a solution and build on it as their knowledge of the content expanded.

The most notable success of the engineering learning community model was the increase in the successful completion rate for Calculus I when compared to previous courses with the same
instructor. An additional unexpected outcome was the increase in class attendance. Results indicated improved student performance in gateway mathematics courses (based on historical data) and improved persistence of students not enrolled in the learning community.

*Introduction of hands-on work into classroom:* Anagnos et al.\(^\text{12}\) described the use of engaging, hands-on projects with a “WOW factor,” into a San Jose State University Freshman Introduction to Engineering course in order to excite students about engineering and to increase student retention and persistence.

The Introduction to Engineering course was redesigned to include a series of projects that engage students in multiple steps of the design cycle. Tasks included brainstorming, conceptualizing, building, testing, evaluating, revising, and communicating their design outcomes both orally and in writing. Projects included a solar cell evaluation, the design, construction and testing of a scaled wind turbine and the design of an autonomous robot. These projects had what they called the “WOW factor”. Most students had never soldered, used a drill press, anemometer, tachometer, dial meter, a rapid prototyping machine and have never built and programmed a circuit board to control a robot. The integration of multiple steps in the design cycle including the hands-on construction of a prototype on an interesting topic was exciting to students.

It was concluded that while a study of this type could not fully evaluate the effectiveness of the course as a factor in the overall increase in the College of Engineering retention rates, it did provide some insight into the effectiveness of engaging and challenging hands-on projects with significant design content to excite and motivate students about the field of engineering. Students enjoyed the projects and looked forward to meeting with their teams to discuss design issues and to test their solutions. Students spent hours in the lab beyond the required three hours per week. The projects with a “WOW factor” appeared to be equally important to other factors such as quality of teaching and grades in STEM classes. A large majority of the students reported that the projects got them excited about engineering and motivated them to continue.

*Improving math skills, Introduction of hands-on work into classroom:* Klingbeil, N. W. and A. Bourne\(^\text{13}\) described the development of a novel first-year engineering math course at Wright State University with the goal of increasing student retention, motivation and success in engineering. Their approach involved the development of a first-year engineering course replacing traditional math prerequisites for core sophomore engineering courses, and a just-in-time structuring of the required calculus sequence. The goal was to increase student success in engineering by removing the first-year bottleneck associated with the traditional freshman calculus sequence.

The first-year engineering math course, Introductory Mathematics for Engineering Applications, included lecture and collaborative laboratory and recitation components. The course addresses only the math topics used in core engineering courses such as physics, engineering mechanics, electric circuits and computer programming sequences. Using an application-oriented, hands-on problem-based learning approach, it replaced traditional math prerequisite requirements for the aforementioned core courses in order for students to advance in the curriculum without first completing a traditional first-year calculus sequence. This structure shifted the traditional emphasis on math prerequisite requirements to an emphasis on *engineering motivation for math.*
The program had an overwhelming impact on engineering student retention, motivation and success at Wright State University. Results of a longitudinal study suggested that the approach had the potential to double the number of the nation's engineering graduates, while both maintaining their quality and increasing their diversity. The results suggested that the impact of the course on student motivation and self-efficacy had contributed to increased graduation rates with the greatest impact on the student groups who stood the most to gain.

*Mentorship program, Interaction with industry:* Johnson et. al.\textsuperscript{14} described a peer mentoring program at LeTourneau University which paired small groups of five to nine “first time in any college” (FITC) students with an upper classman of like major who had successfully completed the first year. Other new retention initiatives included: 1) a faculty mentor program for FTIC students, 2) an industrial mentor program for FTIC students, and 3) two completely redesigned multi-disciplinary first-year engineering practice courses designed to familiarize students with the engineering profession.

*Improving math skills, Providing community-based support system:* Cairncross et. al.\textsuperscript{15} described a six-week summer bridge program developed for first-year engineering students that were not academically prepared to start Calculus I in the fall of their freshman year at the Shiley School of Engineering at the University of Portland. The primary objectives of the program were to increase retention in the engineering program by: 1) allowing students to enter their freshman year academically prepared, 2) provided the information and support necessary for a smooth transition into college, 3) enhance student interest and commitment to the engineering field, and 4) help students build relationships by community-building on campus. Post course surveys indicated that students felt that their expectations had been largely met by the program with a better orientation to the college experience, improvement in math and writing skills, and a better understanding of the field of engineering.

*Introduction to campus resources, Introduction of hands-on work into classroom:* Puccinelli et. al.\textsuperscript{16} described two new freshman engineering courses that were developed at the University of Wisconsin-Madison College of Engineering to increase active learning, retention, and diversity. The courses included a one credit seminar course, Introduction to Engineering, and a two-credit hands-on design course. The Introduction to Engineering course was to be required for all engineering freshman and covered topics such as engineering societies/student organizations, study abroad, campus resources, and career services. Additionally, presentations were made by faculty representing three to four engineering majors per week. These faculty were also asked to briefly present the current research and events within their departments. Subsequent lectures included guest speakers, both faculty and industry, from a variety of engineering disciplines that focused on the challenges within their disciplines.

The two-credit design course “Design Practicum”, was a hands-on design course with lectures and labs that introduced students to relevant topics in engineering that included problem solving, team design, innovation, information technology, engineering, ethics in engineering, community engagement and social responsibility. Online videos, lectures, and tutorials provided a “flipped classroom” style course.
Application of classroom concepts in industry: Saterbak et al.\textsuperscript{17} described an elective course available to all freshman students in the School of Engineering at Rice University where students learned the engineering design process and used it to solve meaningful problems drawn from local industry and international partners. The objectives of the course were to have students learn and practice the engineering design process early in their engineering education in order to increase undergraduate retention in engineering at the university by 10%. The course specific learning outcomes included having students design a product that meets user-defined needs while working in multi-disciplinary teams. Most class periods were split between a lecture in the design process and team meetings to complete the design process and prototype. Students’ knowledge and application of the design process were evaluated at the beginning and end of the semester and showed gains in design process knowledge.

Application of classroom concepts in industry: Bodnar et al.\textsuperscript{18} described a pilot multidisciplinary team-based freshman engineering project program done in collaboration with community sponsors at Texas A&M University with the goal of retaining engineering students. The program did not offer course credit, but focused on students gaining valuable experience involving engineering design, interaction with professional engineering groups, and team-based problem solving. The program was team-based and project-oriented with collaboration from upper-class engineering mentors, engineering faculty and staff, and project sponsors.

The team organization began with a team leader being chosen by the student members of the team. The team leader’s responsibilities included coordinating work between team members, arranging team meetings, and serving as the contact point between the team and the engineering mentors, project sponsors, and the university office responsible for the pilot program. The engineering mentors that participated were upper-class or graduate level engineering students who exhibited leadership qualities in engineering education.

The project assessment was carried out qualitatively, from questionnaires distributed across all participating members of and organizations involved in the project. The results after a single semester indicated that freshman students benefited personally, interpersonally, intellectually, and professionally, and developed teamwork, problem solving, communication, and presentation skills which are highly valued in today’s educational system and industry.

Improving math skills, Introduction of hands-on work into classroom, Providing community-based support system: Erickson-Ludwig et al.\textsuperscript{19} described a summer bridge program oriented toward women and minority students entering engineering at the College of Engineering at Drexel University to improve success and retention. The College of Engineering hosted a “pre-orientation” program that familiarized students with the engineering curriculum and prepared them to succeed in their freshman year through community building and social activities. Program participants showed significant positive outcomes in areas such as problem solving and experimentation, communication, data interpretation and organizational skills.

The program included students studying math, chemistry, and physics. The content consisted of a review of essential high school material, including pre-calculus, basic chemical reactions, and Newtonian physics which were needed for success in college engineering. Students attended evening recitation sections to receive extra help with problems, and during the daytime
participated in hands-on design and computer labs to familiarize them with relevant computer software such as MATLAB, Creo, Excel and Powerpoint. To prepare students for freshman design, design projects included building solar cars and programming Lego NXT robots that competed in a Sumobot challenge. In the evenings and during the weekend, students in the program socialized with Drexel Engineering faculty and students and participated in social activities to build community relationships and discover opportunities at the university and in the city. Peer mentors took students to activities throughout the city, including tours and activities such as miniature golf. Social activities provided a means for students to interact with each other in a casual, non-competitive way while experiencing cultural and historical sites and familiarizing themselves with a new area. It was found participant retention was significantly higher than for students that did not participate in the program.

**Improving math skills, Providing community-based support system:** Bullock et al.\(^{20}\) described the process used and results achieved in transforming first-semester calculus courses at Boise State University from a collection of independent, uncoordinated, personalized sections, into a single coherent multi-section course. The objective was to raise first semester, full-time retention of students in STEM majors. The approach used identical homework assignments with common due dates and times, included a pedagogical approach that included devoting class time to solving problems and working in small groups facilitated by the lead instructor and a learning assistant.

Results from anonymous faculty surveys showed that faculty in the project changed their teaching practices in calculus, observed positive effects in their classrooms, took advantage to learn from their colleagues and acknowledged that their experiences with calculus would transfer into their other classes. Results from student surveys showed that some students expressed discomfort working in groups to solve problems, and not receiving a traditional lecture experience, while others students reporting group work as a valuable experience.

**Improving math skills:** Hensel and Hamrick\(^{6}\) described the implementation of an extended, two-semester, Calculus I sequence at West Virginia University to facilitate success for those students who arrived at the institution marginally prepared for a conventional semester-long Calculus 1 course. The extended Calculus 1 course included the conventional Calculus 1 content, but provided “just-in-time” review of related algebraic and trigonometric concepts, and spaced calculus concepts further apart to make room for the pre-calculus concept review to be interspersed throughout the course.

It was found that students taking the extended Calculus 1 course had a slight advantage in passing Calculus 2 and did so at a higher, but not statistically significantly higher rate. However, approximately 90% of students who earned a B in the extended Calculus 1 course passed Calculus 2 with a C or better, while only 82.4% of the students who earned a B in the conventional single-semester Calculus 1 course earned a C or better in Calculus 2. Therefore, it was concluded that the two-semester extended Calculus 1 course seemed to be a good way to allow weaker math students an opportunity to “catch up” and improve their math skills before moving to the next course.
Improving math skills: Dominguez et al.\textsuperscript{21} introduced an integrated course of physics and mathematics for first-year engineering students at a large private university in northern Mexico. The primary goals of the project were to: a) improve students’ abilities to make connections between physics and mathematics, b) increase students’ motivation to advance in their engineering studies, and c) develop diverse competencies, such as critical thinking and the ability to do collaborative work. The program included the redesign of course content through the integration of physics and mathematics, teaching strategies, classroom environment, technology, and evaluation. The program had good results.

Providing community-based support system: Kukreti et al.\textsuperscript{22} implemented three key strategies to improve retention and student success for ethnic minority, women, and economically disadvantaged or first generation engineering undergraduates at the University of Cincinnati. The three strategies used included: 1) cohort building, 2) networking and 3) a pathway to graduate school. Cohort building included building productive academic relationships among students, between students and faculty, and between students and the university administration. Networking strategies included building a professional network with the people that the students met in their education and future career fields, such as advisors, faculty members, internship supervisors, employers, administrators, volunteer/community activities, seminars/workshops, and conferences. The pathway to graduate school strategy was intended to encourage all promising undergraduate students to apply for graduate school and assisted them in creating a portfolio which would make them competitive to receive financial support.

The three key issues that negatively impact student success in engineering are 1) inadequate academic preparedness from high school, 2) inability of students to adapt socially to their new environment, and 3) having no prior understanding of the expected workload or level of commitment required of an engineering or engineering technology curriculum. These strategies have proven successful in improving first-year success and retention, and were projected to improve graduation rates for the demographic groups supported by the project. Summer bridge course performance was used to place students in the first freshman calculus course, either Calculus 0 or Calculus I. Also, a “structured” freshman year included cohort course scheduling of regular and freshman calculus and physics courses. There was 1) a positive impact of ALEKS on MPT scores during the Summer Bridge Scholars Program, 2) student retention on the average exceeded program goals, 3) there was a higher success rate of STEP students in beginning freshmen math and science courses in comparison to Peer and EASE students, 4) there were lower D, W and F rates of STEP students in beginning freshmen math and science courses in comparison to Peer and EASE students, 5) the end-of-term GPA of STEP students was comparable or better than Peer and EASE students, and 6) it was found that early participation in REU helped students persist an undergraduate degree and gain skills in conducting research, acquiring information, and communicating effectively\textsuperscript{26}.

Introduction of hands-on work into classroom: Walton et al.\textsuperscript{23} introduced a spatial visualization assessment test and a supplemental support course to help those students that did not perform well. Specifically, the Purdue spatial visualization Test: Rotations (PSVT: R) was administered to all students at the Michigan State University first-year engineering course with the goal of implementing spatial skills training to improve students’ retention and performance in engineering coursework. It has been suggested that spatial skill level may serve as a barrier to
entering engineering majors, with those students with poor skills unable to persist long enough in engineering curricula to develop the necessary skills required to succeed. Their initial analysis focused on the success of the course in improving students’ performance on the PSVT: R. Overall, the course helped students to significantly improve their spatial skills as measured by the assessment. It was found that regardless of initial score, gender, first-generation status, ethnicity, and math placement, all students benefitted equivalently from the supplemental course.

Introduction of hands-on work into classroom, Introduction of Technology into the classroom: To make freshman-level engineering courses more interesting, and to expose students to systems level thinking, Pritchard and Mina attempted to integrate the design process during the freshman year. The goal was to assist students in their transition from the high school environment to the university environment by introducing a framework applicable in laboratory courses. By doing so, they created an environment that encouraged experimentation and innovation and permitted students to grow and learn from their mistakes in a fun, hands-on environment. Specifically, they introduced the Arduino-MATLAB experience in the laboratory to meet the changing expectations of freshman students in electrical engineering. This was necessary because the increase in open-source rapid prototyping tools combined with online support made it easier and less expensive for a layperson to undertake electronics design challenges as a hobby which led students to expect to have labs that were very active-oriented and instructional. The addition of the approach to the curriculum was not only effective, but also made learning interesting and exciting for the students.

The lab course involved eleven sessions conducted over a fifteen-week semester and incorporated the use of hardware, software, and design concepts. Each lab involved interactive, discovery-oriented activities and some decision-making processes. They discovered that this approach appealed to a wide range of students with diverse learning styles. The specific topics covered in the lab included systems level thinking, a fundamental understanding of MATLAB, circuit theory and design, the Arduino development platform, and systems design.

Improving math skills, Providing community-based support system, Interaction with Industry: Mathematics skills are very important for the success of students in STEM disciplines. The retention and graduation rates of STEM majors are largely dependent upon their success in passing developmental and lower level math courses. Consequently, Yue developed a NSF funded summer bridge program to improve Associate degree students’ mathematics skills using rigorous mentoring and tutoring practices. The students needed to pass developmental math courses before being able to enroll in STEM courses. Sometimes students ended up having to take these developmental math courses for an extended period of time because they were underprepared. Students could easily change to non-STEM fields that had less stringent math requirements. This behavior enabled students to obtain their degrees faster and could lead to adversely affect retention and enrollment rates in STEM programs.

The bridge course that was developed involved a group of students that participated as a cohort and took introductory math classes alongside their regular classes. Additionally, they received extra exercises and the assistance of faculty mentors and peers. Various supporting services were also incorporated into the program that provided students with individual guidance and
advice from other program staff. Students received a personalized academic plan and class schedules for each semester to help them attain their degree on time. Seminars were held where professional experts from industry made presentations to students in which they described the various career opportunities open to engineers and discussed their personal experiences after transferring to four-year college degree programs. These supporting activities motivated students to stay in the STEM fields. It was found that students that participated in the bridge program outperformed other students in summer math courses and in higher level math courses.

Introduction of hands-on work into classroom: Chin et al.\textsuperscript{27} described how hands-on group projects were introduced in the freshman year rather than the sophomore year to motivate students and provide them with a reason to study engineering, rather than to only focus on the theoretical aspects of math and physics.

These projects were designed by different engineering majors. Students completed a seven-week core engineering fundamentals course in the fall semester of the freshman year which included hands-on application of classroom knowledge to solve group-based micro-projects. This approach demonstrated the real-world application of theoretical concepts which had the effect of bringing classroom lectures and concepts to life.

Subsequently, for the second half of the fall and first half of the spring semester, students worked on two hands-on mini-projects. These projects were interdisciplinary in nature and exposed the students to a minimum of two major disciplines. Examples of these mini-projects include: a) application of acoustic technologies in predicting structural failure, 2) biofuels process and sustainability, c) electric car design, d) robotics and MATLAB programming; e) the load deflection character of a SMARTBEAM, and f) an adsorption-drinking water treatment process.

On the completion of the mini-projects, students selected their intended major by the second half of the spring semester. This process enabled them to make a more informed and experience-based choice.

Introduction of technology into the classroom: Similarly, Puccinelli and Murphy\textsuperscript{28} introduced the use of cutting edge technology and resources in their collaborative, freshman year Introduction to Engineering Design course which prepared students for a successful engineering career. A collaborative, supportive environment had shown to increase retention and graduation rates and created a more positive learning experience for students where friendships formed in this environment transferred to other courses.

A unique aspect of the course was student use of LabArchives electronic laboratory notebooks (ELN) to record the design process that they experienced. This included brainstorming, understanding the design specifications, performing the literature review, doing the design evaluation, and the implementation of the design. Based upon these records, students wrote a semester-end report and made a presentation to their peers. The design notebook contained the individual contribution of each individual student.

Design notebooks were implemented to replace paper notebooks because there were nearly 1000 students taking the course and grading of the reports was a tedious task for instructors, faculty,
industry personnel, staff and student assistants. There was an average of thirty-three reports per laboratory session. The notebooks were a crucial component of the project and formalized and safeguarded each individual student’s intellectual contribution. Furthermore, students used various forms of technology in their designs which were hard to print or include in a hard-copy notebook.

Feedback from student assistants and instructors revealed that the LabArchives ELNs were easy to use, facilitated the sharing of information, and had good organizational capabilities. Additionally, the ELNs made the grading process much more convenient than when paper notebooks were used. The ELN was divided into folders that recorded every step of the design process, and permitted instructors to determine if students had created and uploaded correct entries. The ELN could also be viewed any time without creating an obstacle to student progress, as opposed to paper notebooks which could only be viewed when students submitted them to instructors.

Introduction of hands-on work into classroom: A new Introduction to Mechanical Engineering course was designed and implemented at the Citadel\textsuperscript{29} to provide freshman students a basic understanding of power and energy, manufacturing, aeronautics, composites, and mechatronics. The course provided students a general understanding of the different areas of mechanical engineering and enabled them to make an informed decision while selecting electives. It also clarified students of any misconceptions regarding the engineering discipline and provided them with a realistic picture and awareness of the engineering field. It also introduced freshmen to basic engineering concepts and informed them of the available internship and career opportunities after graduation. It exposed them to the principles of ethics in engineering and informed them about the requirements they would need to satisfy to get their professional engineering license. It trained them on the softer skills and qualitative aspects of success in their discipline such as developing an attitude of becoming lifelong learners, giving back to their community and profession via service, effectively managing their time, and pursuing a path of consistent career development.

The course attempted to increase retention and student interest by developing an exciting introduction to the mechanical engineering program and combined both individual and team-based homework, projects and presentations, theory and hands-on work, and encompassed different areas of mechanical engineering to give them a broad view.

The engagement of students in an active learning environments from the start of the freshman year helps keep them motivated and excited and gives them the drive necessary to get through their core courses (mathematics, humanities, basic science, and statics and dynamics) before they start their mechanical engineering courses in their third year of study. The excitement they experienced in the hands-on, collaborative active learning experience during their freshman year helped them to cope with the significant life changes during this period.

Examples of exercises that students were required to complete are:

Aeronautical: After a short lecture on the basics of flight, students were required to develop the most efficient plane design from six options available to them. The plane was made of materials
such as paper, tape, etc. where each material had a cost. The goal was to minimize cost and maximize distance flown.

Manufacturing: Students were taken on a field trip to the campus facilities repair shop where they learned about different equipment.

Composites: An industry expert was invited to make a presentation in this area.

Power and Energy: Students iteratively arrived at an optimum design of a gear train using Lego to lift a two-pound weight.

Mechatronics: Students attended a lecture on mechatronics and its applications.

Upon survey-based student feedback, it was learned that exposing students to the five aforementioned subject areas within mechanical engineering assisted them in making an informed decision regarding their choice for the area of study. Additionally, it was found that students did not want an easy course; they were aware of the challenges that lay ahead them as engineers. However, they did enjoy the excitement that the course added to their curriculum, while preparing them for their future career. The feedback reflected student’s interest in the course and reinforced the strong and positive elements of the course’s structure.

Improving math skills, Providing community-based support system: Weatherton et al.\textsuperscript{30} tried to increase retention by providing freshman students with academic support services in calculus and basic mathematics. They studied the retention and performance of incoming freshmen that were involved in one of four freshman interest groups (FIG), called FORCES (Focus on Retention in Cohorts of Engineering Students). They compared the performance of these students with students in the engineering school as a whole, and in three other FIGs. The focus of the study was to comprehend the effect of academic support services on freshman retention. This was a NSF-funded study and was performed over the summer before the fall of freshman year.

The FORCES program focused on calculus training, since it is considered to be essential to success in an engineering program. Students that were a part of this program were required to show that they were adequately prepared for calculus by the fall semester of freshman year by performing reasonably well on the college’s Math Aptitude Test (MAT), which tested students in algebra, pre-calculus, and trigonometry, or by completing a course called “Jump Start Math” (JSM) which combined pre-calculus 1 and 2 into an eight-week summer course.

Additionally, tutors conducted study sessions for groups of four to five students which were focused on teaching and answering questions related to Calculus 1. Finally, the “Guaranteed 4.0” program provided students with an approach to prepare for classes and improve their ability to learn.

The researchers found that “Jump Start Math” did not show any improvement in GPA, calculus performance or retention. However, students felt that it helped them prepare for the challenge of college coursework and to tackle calculus courses in the future. Students found the group study sessions to be helpful, but were not impressed with the tutors, possibly because the tutors might
not have been specialized in calculus or did not have the best interpersonal or communication skills. They felt that the “Guaranteed 4.0” program helped them prepare academically, but they were unable to apply it in their calculus courses.

*Introduction of hands-on work into classroom:* Santiago and Abioye\(^{31}\) introduced a new, cost effective module in electronics to students in a first-year engineering program at a land grant university. The module was integrated into an engineering problem solving course and included reading material, practice problems, hands-on activities and a project. The goal of this teaching innovation was to address the problem of attrition in engineering programs. The researchers attempted to demonstrate that engineering can be fun, exciting and interesting by incorporating a hands-on component in an engaging, student-centered environment. There were 42, first-year students enrolled in the engineering problem-solving course that participated in this study. It was found that the students were prepared for calculus but had not yet entered into a major engineering discipline.

The module was delivered over a three-week period across five lectures and was added to concepts taught with Microsoft Excel. Before the first lecture, students were required to prepare for the module by reading a handout prepared for the module. Students were engaged in the hands-on design of various circuits based upon instructions they received during the lectures. Subsequently, there was a group project in which groups of two students designed and constructed an electronic sensor to measure the water level inside a tank. Students also performed some Excel calculations while completing the project, thereby gaining experience using the tool.

Since this module involved students working in pairs to design simple circuits, the initial cost of the project was only about $10 per student, making cost effectiveness an important feature of this module. Reuse of materials after the completion of the course further reduced costs.

Survey feedback revealed that the module was appreciated by students, who showed nearly 100% attendance throughout its’ entire duration. Additionally, lectures were interactive and the students asked intelligent questions that were relevant to the material being taught. Even students that didn’t intend to major in electrical engineering felt that they gained by learning about circuits and reported an increased interest in engineering as a consequence of their participation in the study.

*Providing community-based support system:* Erickson-Ludwig and Kelly\(^{32}\) implemented the Paul Peck Scholars Program into the engineering curriculum at Drexel University. The Paul Peck Program is a peer mentorship program offered in the first year of study that subsequently grows into a leadership program. It has been found that peer education and mentorship programs are very useful in creating an engaging environment for students on campus and helps them persevere through graduation. Students that were associated with a mentor addressed and resolved concerns more frequently than those without a mentor. They also tended to persist at a higher rate than those that were not mentored.

In its incorporation at Drexel University, first year students were allocated a mentor from a higher class. These freshmen had the opportunity to continue to participate in the program after
their first year by serving as upper-class mentors and leaders for the next generation of freshmen. The program improved engineering students’ soft skills, their leadership skills, and taught them that good communication skills are essential to lead people.

To implement the program in the engineering school, first year students were permitted to freely choose to participate in the program and were informed about it on the program’s website, on incoming and current student pages, and via the distribution of newsletters for freshmen and sophomore students. Students interested in serving as mentors were selected on a competitive basis.

Freshmen submitted a short application that described what they desired in a mentor, and elaborated on what was their most challenging high school experience. Upper-class students were also required to submit an application that described what qualities they possessed that could make them a good mentor and their leadership skills and how they would motivate students to persevere through their degree programs. The final mentors were selected based upon an interview process.

The program had several beneficial outcomes. Specifically, in the context of retention, it was found that 82.2% of students that participated in the Paul Peck Program persisted in their engineering discipline, as compared to a 52% retention rate among students that did not participate in the program. It was believed that the combination of peer mentorship and skills development contributed to an improvement of participating student’s GPAs and higher persistence rates.

Introduction of hands-on work into classroom: In keeping with recommendations from engineering colleges and the National Science Foundation, Stringer described the beneficial implementation of toys as a tool to teach freshmen engineering design principles using a hands-on, team-oriented environment at Penn State University. The approach attempted to reduce the intimidation students might feel toward engineering and attempted to create a comfortable environment. They found that one-third of students dropped out of engineering programs overall. However, they also found that after finishing their second year, very few students dropped out. Hence, they concluded that the first two years were crucial to maintaining student retention in their engineering program.

Penn State’s Introduction to Engineering course offered during the freshman year placed an emphasis on hands-on work performed in a collaborative environment in order to increase student engagement and retention. Important engineering design ideas such as manufacturing, safety, cost analysis, materials selection, and marketing were explained to the students in lectures. Students were required to apply these concepts in developing technical solutions for a complex toy design project. Students typically succeeded in constructing a working prototype toy. The toy design project was incorporated into an existing course in engineering design which was a six-hour per week lecture / laboratory course that taught the basics of engineering design. Previously, the course involved requiring students to work on theoretical engineering design problems on paper that involved the application of basic engineering and math concepts. Projects of this type were very difficult for students to conceptualize due to their abstract nature and students felt that such projects produced no concrete product, making it hard for them to feel
a sense of tangible accomplishment at the end of the semester. The toy design project, however, enabled students to create a tangible product at the end of the semester which they presented to their peers. This type of project improved their skills and knowledge which assisted in improving retention in the engineering program.

A total of 48 students participated in the study and were divided into teams of four members. The groups were given between three to four weeks to complete their design and spent approximately 18-20 hours in class on the practical aspect of the project. Each team was assigned a different toy to assess and were given a design criterion that outlined specific areas of interest that they were required to explore during the investigation. At the end of the project, students presented their conclusions relevant to their allocated design rubric, and displayed a working prototype to the campus community.

_Providing community-based support system:_ Welch et al.\(^{34}\) implemented the well-known idea of using supplemental instruction to improve freshman retention levels by approximately 20%. Instructors have credited supplemental instruction at the freshman and sophomore levels as a motivating force that encourages students to persist in their programs.

The Supplemental Instruction (SI) program described by Welch et al.\(^{35}\) catered to students in high-risk courses and provided them with the opportunity to attend tutoring sessions throughout the semester that were dedicated to explaining the course material in depth in order to equip students with a more clear and fundamental understanding of the subject matter. Students participated in the program on a voluntary basis at no cost to themselves, although extra credit was offered in some cases as an incentive to attend the tutoring sessions. The sessions were conducted in groups. Each session was conducted by a student that had previously passed the course with a minimum of a “B” grade. Two, four-hour sessions were held each week. Appointments were not required to attend the sessions and the interested students were free to walk into a session. The sessions assisted students to stay up to speed with the course and master difficult concepts in an active-learning environment.

The student leader running the SI sessions worked in close collaboration with the faculty member teaching the course in order to identify areas in which the students required improvement. This was accomplished by the student leader and faculty member spending time reviewing homework, quizzes and tests over the course of the semester, and simultaneously observing student performance and understanding the challenging concepts encountered during regular class hours. The course material covered in the SI sessions was presented in a manner different from that in which the faculty member presented it in class and did not involve a simple repetition of the classroom lecture. Material was presented from a different perspective to help students understand it better.

Based upon the data collected, it was concluded that the SI program was successful in its mission. It led to lower DFW rates (“D” = D letter grade, “F” = Fail, and “W = Withdrawal). The SI program also had the effect of giving students the opportunity to persist in their chosen fields which led to increased student retention. A key feature that correlated to a successful SI program was the active participation of the SI student leader that conducted the sessions. It was necessary for the student leader to closely follow the course material by attending class, making
it possible to closely relate the SI sessions to the material covered during regular classroom hours by the faculty member. Additionally, active promotion of the program was linked to its success.

Discussion and Conclusions

This section summarizes the retention results from the different techniques described in this paper and includes data on retention percentages, scope, and duration of the different strategies. Not all the papers that have been summarized had this data. Hence, only those papers that incorporated relevant data are highlighted in this section.

The STEP program described by Kukreti22 incorporated three strategies which included cohort building, networking and a pathway to graduate school over a six-year period. It involved the participation of 199 students and resulted in the graduation of 131 students, leading to an average graduation percentage of 65.8% over the duration of the program.

The Paul Peck Program32 implemented upper-classmen as mentors. It was implemented in 2009 and by the Spring of 2014 approximately 125 students participated in the program. Data available as of 2012 showed that the program resulted in participants having a retention rate of 82.2% in the engineering college. This was higher than the 52% retention rate of non-participants within the engineering college.

Welch et al.34 succeeded in increasing student retention by nearly 20% by using supplemental instruction. The program was implemented in the fall of 2012 and data was available for three subsequent semesters until the fall of 2013. A total of 356 students were impacted by this strategy.

The JITM program by Shadaram10 was initiated with 12 pre-freshman students in the summer of 2008 and primarily focused on improving freshman math skills. It resulted in a third-year retention percentage of 72%, which was higher than that attained by the traditional cohort of students in the school, which had a retention rate of 48%.

The freshman engineering courses described by Puccinelli16 showed that the overall retention rate of all engineering students at the university increased from 57% in 1985 to 68% in 2012. In 1985, the engineering program had a total of 822 students and in 2012 (the final year in which data was available) there were a total of 928 students.

Erickson-Ludwig’s19 program to increase retention of women and minorities in engineering was started in 2011 and focused on community building and social activities. Two years of data was collected and 44 students participated in the program. In 2011, the program showed a retention rate of 83% for those who participated in the program which was a higher rate than the overall college of engineering’s retention rate of 68%. It was also higher than the retention rate of 62.1% for women and minorities in the college of engineering that did not participate in the program. In 2012, the program showed a retention percentage of 92% for those who participated, which was higher than the overall college of engineering’s retention rate of 76.8% and higher than the retention rate of 78.5% for women and minorities that did not participate.
It has been shown by the reviewed literature that most students withdraw from their chosen program by the end of the first or second year. The reasons for this attrition typically include a lack of preparation in calculus and physics, pressure due to the transition from a high school environment to a college environment, a lack of interest in the chosen major, and inadequate teaching techniques. Several strategies have been employed thus far to increase retention in engineering programs. These strategies can be implemented to increase retention in engineering programs and can be broadly classified as follows being focused on improving math skills of incoming freshman, enhancing the sense of community and support for incoming freshman, improving faculty teaching techniques, retaining student interest in their chosen discipline by solving practical engineering problems and incorporating more hands-on components into the classroom.

References


