122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11454

A review of practical design integration methods for existing engineering curriculum

Elissa T. Morris, Texas A&M University

Elissa Morris is a third-year PhD student in mechanical engineering at Texas A&M University. Her graduate advisor is Dr. Daniel A. McAdams, and her research focuses on the development of bioinspired design methods for self-assembling systems as well as topics in engineering education. Her anticipated graduation is in August of 2016. She received her Bachelor of Science degree in mechanical engineering from the University of Texas at San Antonio in 2011.

Dr. Daniel A. McAdams, Texas A&M University

Dr. McAdams is an Associate Professor of Mechanical Engineering in the Department of Mechanical Engineering and Graduate Program Director at Texas A&M University. He joined the department in January of 2008 after serving as an Associate (2005-2007) and Assistant Professor (1999-2005) of Mechanical Engineering at the Missouri University of Science and Technology. He received his Ph.D. from the University of Texas at Austin in 1999. He teaches undergraduate courses in design methods, biologically inspired design, and machine element design and graduate courses in product design and dynamics. Dr. McAdams research interests are in the area of design theory and methodology with specific focus on functional modeling; innovation in concept synthesis; biologically inspired design methods; inclusive design; and technology evolution as applied to product design. He has edited a book on biologically inspired design.

A review of practical design integration methods for existing engineering curriculum

ABSTRACT: Design is a fundamental aspect of engineering education. Traditionally, students are challenged with acquiring a skillset for design during their first year in introductory design courses and their last year in senior capstone design courses. In most engineering undergraduate curricula, throughout the sophomore and junior year, design is not necessarily a focus. Some efforts have been made in an attempt to incorporate design through every year of the engineering curriculum. Some of these notable efforts include the Conceive-Design-Implement-Operate (CDIO) initiative implemented at various universities and the Institute for Design Engineering and Applications (IDEA) at Northwestern University, both of which showcase a completely restructured curriculum. While the CDIO framework and the IDEA program have been proven effective, not all institutions desire or are practically able to drastically restructure their curriculum. Therefore, practical methods of design integration to existing curriculum may prove more useful to these institutions. This paper includes a review of practical methods used to incorporate design in various engineering courses. Specific design integration methods reviewed in the paper include examples of project-based learning, inquiry-based learning, design competitions, case study modules, reverse engineering, and design-based learning. Assessments of these methods are qualitative in nature thus the comparisons are also qualitative. The goal of this research effort is to provide a brief review of current methods found in the literature. While a qualitative comparison of the methods is discussed, providing assessments of each method lies outside of the scope of this work.

History of engineering education and the role of design

Engineering education is continually evolving. The purpose of formal engineering education in the United States, at its inception in the early 1800s, was to promote "the application of science to the common purposes of life" [1]. Engineering educators in the 1800s were merely practitioners and relied on their professional, hands-on experience to train their students. Interestingly, engineering was not viewed as an esteemed academic endeavor at the time. The Homestead Act, the construction of the Union Pacific Railroad, and the Morrill Land Grant Act led to rapid economic development in the late 1800s, and the amount of engineering schools significantly increased across the nation. Engineering curricula during this period was based on specialized technical training to allow graduates to become immediately useful in industrial design careers and to efficiently meet the needs of the quickly developing economy. This trend of education continued and "by 1900, it was generally recognized that American laboratories and methods for the teaching of engineering were not surpassed and often not equaled in any other part of the world. This could not be claimed, however, for much of the theoretical instruction in design" [1]. Despite the weakness of design theory instruction, the focus on applied learning and hands-on experience in engineering schools sufficiently met the needs of the booming manufacturing, automobile, aviation, and electrical industries of the time. After World War I, engineering education shifted from the applied, specialized training to a more general training focused on science, humanities, and the administrative and professional responsibilities of the engineer. Engineering programs across the nation were simplified to create curricula useful in a wide range of occupations. The effects of World War II caused yet another shift in engineering education. The rigorous study of scientific theory and mathematics became the foundation for engineering education to meet the demand for technological advancement in nearly all engineering branches.

This educational foundation remained prominent throughout the “Space Race” with the Soviet Union. In 1955, the acclaimed Grinter Report was issued and provided a thorough evaluation of current engineering education methods and made recommendations for the future of engineering education with the growing economy and rapid scientific and technological developments in mind. The report claimed that engineering curricula should focus on the studies of “humanities, social sciences, mathematics, and basic sciences, engineering sciences, engineering specialty subjects, and electives” [1]. The guidelines in the Grinter Report impacted engineering education until the 1990s when a call for curriculum reform was made [2]. It was argued that engineering curricula heavily emphasized scientific theory while abandoning engineering design and creative synthesis [2]. The hands-on training and applied learning methods of earlier engineering education were re-introduced to the curricula, and design became a major focus in the reform of engineering education. The Accreditation Board of Engineering and Technology [3] influenced the development of capstone design courses offered to senior-level students to meet the need of design implementation in engineering curricula [4]. Capstone design courses enable students to become familiar with the engineering design process through a class project requiring the application of knowledge and training received in freshman, sophomore, and junior level courses. While the addition of capstone design courses has successfully integrated the design process in engineering education, it has been argued that design integration throughout the entire curriculum is necessary [5-7]. Several institutions have taken this notion to heart and have completely restructured their curriculum around design.

Examples of completely restructured engineering curricula with design foundation

Researchers at the Massachusetts Institute of Technology developed and implemented the Conceive-Design-Implement-Operate (CDIO) initiative to resolve two irreconcilable needs: teaching students how to apply technical knowledge to real world problems and equipping students with the personal, interpersonal, and system building skills necessary to function in the professional engineering environment [8]. The CDIO initiative requires curriculum reform and maintains twelve standards related to syllabus outcomes, integrated curriculum, design projects, workspaces, integrated and active learning experiences, faculty training, student evaluations, and program assessments [9]. Graduates of institutions that follow the CDIO framework are expected to fully understand the product-system lifecycle which consists of four metaphases: conceiving, designing, implementing, and operating. These four metaphases form the context of engineering education within the CDIO initiative.

Northwestern University established the Institute for Design Engineering and Applications (IDEA) to benefit students with a comprehensive, inter-disciplinary design experience throughout their undergraduate studies. IDEA offers a design certification program for students after completion of several design-related courses, an engineering design portfolio, and multiple design projects [10]. The portfolio must demonstrate the students’ proficiency in the design process, design analysis, prototyping and implementation, modern software tools, and effective communication. To enhance communication skills and provide quality instruction and feedback, students collaborate with graduate students, post-doctoral researchers, faculty advisors, and industry professionals to complete projects. Graduates of IDEA are trained to become competent designers and reflective practitioners of engineering. They acquire a well-rounded design skillset that helps them solve difficult design problems, reflect upon their methods and solutions, and make revisions to their solution approach if required [10].

While these efforts are notable, perhaps ideal, examples for engineering curriculum with a design focus, their approaches are not easily implemented. A collaborative effort is required to implement these programs. Faculty, administrative staff, students, and industry professionals all contribute to the development and implementation of the CDIO framework and the IDEA program. While these two programs effectively provide students with a comprehensive engineering design skillset, the collaborative efforts required to implement such completely restructured curricula do not practically meet the needs of all engineering institutions. Practical design integration methods that do not require complete curriculum restructuring may better serve these institutions.

Examples of practical design integration methods for existing engineering curriculum

Embracing curriculum reform is not an easy task. Engineering faculty desiring to integrate the design process throughout their curriculum must develop innovative and insightful ways to do so without drastically changing existing curriculum. Slightly modifying the content of an engineering course is perhaps the most realistic approach [11, 12]. Several examples of practical design integration methods are provided to meet this need. Papers cited either provide qualitative assessments which are difficult to normalize, or they do not provide assessments at all. Therefore, providing an assessment of these methods lies outside of the scope of this work.

Project-based learning

Perhaps the most effective way to teach engineering design is through project-based learning methods. Project-based learning allows "students to learn design by experiencing design as active participants" [13]. The literature suggests that improvements in retention rates, student satisfaction, and student learning are observed when project-based learning methods are used [13]. The senior level capstone design course is one example of project-based learning. Design projects can also be incorporated into other engineering courses as demonstrated by the following examples.

Libii at Indiana University-Purdue University at Fort Wayne has successfully integrated design experience into a fluid mechanics course [14]. Open-ended problems are presented at the start of the course, and students are required to select one problem as the focus for their design project. Three options are available and consist of the following: design a device that demonstrates a concept learned in class, design an experiment that demonstrates a concept learned in class, or redesign with the intent to improve an existing experiment by identifying flaws, developing a solution approach to fix the flaws, and demonstrating the proposed solution [14]. Preliminary and final reports, oral presentations, and design demonstrations were required for all projects. Some of the advantages observed by this design integration method include students becoming more familiar with the design process, exposure to teamwork experience, further development of technical writing and oral presentation skills, and collaboration experience with engineers in industry [14]. Some of the disadvantages of design integration into this fluid mechanics course include confusion among students regarding the design process, lack of project funding, lab access challenges, and difficulties among students in determining a realistic project scope [14]. Another significant disadvantage was the need to reduce the amount of topics covered in the course by three chapters to allow sufficient class time for the design projects. However, students showed greater interest, increased participation, and greater depth of technical knowledge as a result of these class projects. Due to the success of design integration, the class projects remain a permanent part of the course [14].

Miri and Fu at the University of North Carolina provide a slightly different example of design integration through the project-based learning method [15]. Electrical engineering students in a senior-level electromagnetic devices course are given nine days to complete a design project. The same problem is given to each student to complete. To illustrate, the design specifications are provided [15]:

In a high precision electronic instrument, it is require to have two isolated power sources. This requires the power supply transformer to have two secondary windings. The design requirements are for one primary winding at $V1 = 120V$ and two secondary windings each at V2 = 10V while delivering I2 = 0.5A at 60 Hz. The maximum space available for the transformer on the power supply board is, in inches, 2 × 1.5 × 1. Design this transformer in enough detail such that a prototype can be constructed directly from your design. That is, you must provide design information such as core material, lamination type and size, standard bobbins to be used, number and thickness of laminations (this determines the core cross-sectional area), wire sizes for the primary and secondary windings, and the primary and secondary number of turns. Make sure the flux leakages (i.e., the fluxes not confined to the core) are minimized. Analyze your design using the finite element program provided, and discuss the results. Your analysis must include the calculation of the core and leakage average flux densities.

The students are challenged to apply learned course content to an open-ended design task using the given specifications and an analysis program provided by the instructor. A thorough design solution is provided by the professors for reference [15]. After completion of the design task, students build a prototype, perform testing, and report the results [15]. The sacrifice of some course content was made at the expense of the design project. However, Miri and Fu suggest that "teaching fundamentals through design is far more valuable than teaching any specific subject" [15]. Before considering implementation of similar class projects to teach engineering design, it is recommended to work out the entire design task before assigning it to students, to ensure the design project is relevant to course material, to ensure the students can complete the project within a relatively short time, to select a design task that can be prototyped and tested, and to make all necessary manufacturer's catalogues available to students [15].

Several other examples of design integration through project-base learning methods are found in the literature. Some of these examples include the following: Yoder employs an open-ended design project in a sophomore-level electrical engineering course [16], Hadim and Esche report of their success with implementing project-based learning methods in a freshman-level mechanics of solids course and a junior-level mechanisms and machine dynamics course [17], Abu-Mulaweh and Al-Arfaj tasked students with designing a refrigeration system in a thermodynamics course [18], and Newcomer teaches automatic control theory to juniors and seniors through several semester-long design projects [19]

Inquiry-based learning

Inquiry-based learning challenges students to create knowledge instead of receiving knowledge from professors. This non-traditional teaching approach requires students to search for and synthesize data relevant to a particular problem [20]. Students show interest in a project or class topic and independently find solutions and explanations for the project or phenomena and are expected to draw their own conclusions regarding the subject matter. "Their curiosity is satisfied when they construct mental frameworks to explain the researched phenomena, and thus meaningful learning is assimilated" [20].

Tamir at the Hebrew University of Jerusalem implements inquiry-based learning by showing his students a brief video of a biological process and proceeds to ask them questions regarding what they observe [21]. Students are told to write down their observations and share their thoughts with the class. Because no wrong answer exists, all plausible observations are respected. However, students are encouraged to critique the observations of their peers and propose alternative solutions based on the class discussion. The professor does not lecture on the topic. Instead, the students are the main contributors to learning while the professor gently guides the investigative class discussion following a prepared script. A lesson script example can be seen in [21]. As students begin to ask more questions, a more detailed analysis is achieved. While this particular example is focused on biology, the inquiry-based learning module can be modified to address the engineering design process. This approach "leads to the invention of concepts as well as to discussion which clarifies the meaning of the concepts and their applications" [21].

Design competitions

Design competitions are similar to project-based learning methods because students are tasked with a design project. However, design contests allow students to experience the competitive aspect of engineering, which can lead to increased motivation for the project and a greater excitement for learning.

Gregson and Little at Dalhousie University use contests to incorporate design in a junior-level analog electronics course [22]. The students are tasked with designing and building analog circuitry used to autonomously control small robotic vehicles. Material covered in lecture is used by the students to "design, implement, and test circuitry for controlling motor direction and speed, low-level signal conditioning, sensing light, metal, obstacles, etc., voltage regulation and power supply conditioning, implementing control strategy, and generating timing signals" [7, 22]. The contests expose juniors to the design process by providing experience in concept identification, knowledge acquisition, and exercising judgment. The contest challenge changes from course to course. One year, students were required to guide their robotic vehicles through a maze. This particular competition drew hundreds of spectators, including local television media. Gregson and Little argue that successful design contests should be a spectacle to motivate current students, to attract future students to the program, and to raise interest in the community. Students report that the contest increased their interest in electrical engineering, was useful as a learning tool, and was a valuable investment of their time. Students also express that the contest motivated them to learn, provided them with a good engineering experience, and was more effective for learning course material than conventional laboratory sessions. One drawback of this approach is the sacrifice of depth in some course topics to allow more time to teach contest-relevant material. However, they suggest that these drawbacks can be alleviated with more careful course planning [22].

Impromptu design contests have also been used to achieve design integration in existing courses [23]. Impromptu design contests are useful because they do not require a significant amount of class time compared to other design integration methods which require an entire semester. They also focus on the application of one or two engineering science concepts whereas semester-long competitions or projects require the application of numerous topics taught throughout the course [24]. Nevertheless, students are still introduced to important design concepts such as the basic design process, decision-making, and optimization [24]. Students are also challenged to refine their skills in creative thinking, problem solving, and team building [25]. Students are given a problem statement, materials, and a time limit (e.g., one class period) to design and build their solutions

[23]. The following problem statement shown in Figure 1 serves as an example of an impromptu design exercises that could be used in a mechatronics course:

> Need Statement: Hot coffee can cause serious burns and thus needs to have its temperature monitored
>
> Problem: Design a temperature measurement system that can measure coffee temperature.
>
> Scoring Metric: The design will be judged based on their accuracy (when compared to a mercury thermometer) over a range of temperatures from ice-water to hot coffee.

Figure 1: Example problem statement for impromptu design exercise [23].

Students would design and build sensor circuitry to solve this problem using standard electronic equipment such as temperature sensors, capacitors, resistors, and microcontroller prototyping boards. Time is made for reflection and students are tasked with creating a list detailing their problem solving method. This reflective period provides students with a familiarity of the engineering design process. Students then share their solutions and design process steps with the class. Impromptu design contests have been implemented into various courses such as introductory design for freshman-level students, mechatronics for mechanical engineering students, mechanics for civil engineering students, and biomaterials for chemical engineering students [23]. Assessments indicate that impromptu design contests help familiarize students with the design process and that students enjoy these exercises [24].

Davis and Masten at Michigan State University also report of design integration through contests with a focus on multidisciplinary teamwork [26]. Rather than integrate the design competitions into a core course, the competitions are voluntary, can be taken for credit or simply as an extracurricular activity, and are open to engineering and non-engineering students. The objective of these competitions is to provide students with a foundation in design and multidisciplinary teamwork [26].

Case study modules

Using case study modules as a practical design integration technique involves reviewing and evaluating the decisions and experiences of others [27]. Cases can present open-ended, ill-defined problems or situations that are historically accurate or completely fictional. Students participate by assuming the role of the engineers or designers described in the case and by evaluating the information they were given and the decisions they made.

Gorman et al. at the University of Virginia uses case study modules as part of an invention and design course [28]. The course is offered to both engineering and non-engineering students to create a multidisciplinary teamwork scenario in the class. One of the modules used is a telephone invention case involving historical figures like Alexander Graham Bell, Elisha Gray, and Thomas Edison. Bell is credited with the invention of the telephone, while Gray and Edison were his competitors at the time. Students are required to assume the role of an additional competing inventor and attempt to patent and prototype their suggested design improvement. Students are given sections of Alexander Graham Bell's notebook to provide insight from the inventor himself. Some class lectures are also dedicated to providing comparisons between the designs of

Bell, Gray, and Edison. Through the patenting process, students gained experience in written and oral communication, while the prototyping process gave students hands-on experience seeing their ideas become reality. Other modules involve a computer simulator for driver's education, an energy-efficient home, and medical decision support systems [28]. Various case study modules can be integrated into existing core courses to teach engineering science concepts. For example, the telephone invention case can be implemented in an electrical circuits course to help reinforce technical concepts learned in class [27]. Assessments indicate that despite enduring difficulties and frustrations associated with the design process, students view the experience as rewarding and useful [28].

Reverse engineering

Reverse engineering, also known as mechanical dissection, is a teaching method whereby students learn the design process through product disassembly and redesign. During this process, "a product is predicted, observed, disassembled, analyzed, tested, 'experienced,' and documented in terms of its functionality, form, physical principles, manufacturability, and assemblability" [29]. It has been argued that traditional methods for teaching engineering design are compartmentalized and do not encourage reflective practice. Reverse engineering addresses these issues by revealing the design process in an incremental fashion and demanding reflection and observation during product redesign [29]. Similar to how a student can understand and solve engineering homework problems by working backwards from the solution, reverse engineering enhances students understanding of the design process through product disassembly and redesign [29]. This approach has been shown to foster integrative design thinking and increase retention rates of engineering students [29].

Aglan and Ali at Tuskegee University developed an entire course dedicated to reverse engineering [30]. The course is targeted toward freshman and sophomore students with an objective to "provide hands-on dissection experiences that will aid engineering students in developing an awareness of the design process and introduce them to the vocabulary of mechanical systems" [30]. Throughout the course, students disassemble various products including a weighing scale, a money sorting machine, a gasoline engine, and a centrifugal pump [30]. While these disassembly projects make up an entire class, each product can be integrated separately into an engineering core course. For example, the disassembly of the weighing scale helps students understand the equilibrium of forces and moments which can be useful design integration in a statics course. The money sorting machine emphasizes principles covered in a dynamics course such as the conversion between potential and kinetic energy. The gasoline engine disassembly helps students understand the role of carburetors, cylinders, pistons, connecting rods, crankshafts, camshafts, and valves as discussed in a thermodynamics course. Lastly, the centrifugal pump disassembly can be integrated into a fluid mechanics course to familiarize students with the design of impellers and how the pump increases fluid pressure through centrifugal force [30].

Design-based learning

Design integration methods generally rely on engineering science as a foundation to integrate and teach the design process. In design-based learning methods, the tables are turned – design is used to teach engineering science.

The literature contains numerous examples of design-based learning approaches implemented in secondary education [31-36]. For example, Kolodner at Georgia Institute of Technology uses the design-based learning approach to teach science to middle school students [31]. Students engage in a design challenge which "provides a reason for learning the science content" and "provides a natural and meaningful venue for using both science and design skills" [31]. Students gain a better understanding of scientific concepts while testing their designs. Teamwork and communication are fostered by these design challenges which also helps students come to scientific conclusions collaboratively [31]. It has also been shown that design-based learning methods help students understand science concepts well enough that teachers are able to move at a faster pace and cover more content in class [35, 36]. Interestingly, design-based learning methods are not commonly utilized or systematically studied in higher education [37].

Discussion

While the practical design integration methods discussed are presented separately, they are all connected in some way and can be used in conjunction with one another to effectively teach engineering design. For example, inquiry-based learning methods can be implemented with project-based learning, case study modules, and reverse engineering. A design contest is essentially an example of the project-based learning method presented in a competitive context. Reverse engineering is related to the design-based learning method because it requires the disassembly and redesign of a product in order to provide greater understanding of engineering principles. Case study modules can be used in conjunction with project-based learning and design-based learning methods to encourage reflective practice during the design process. In summary, the teaching strategies presented in this work can be considered as a family of practical design integration methods that are related in various ways and can be used separately or together for engineering design education.

Selecting appropriate design integration techniques for a given engineering course depends on the course content and the desired learning objectives. Each method discussed has unique advantages. Providing an assessment of the effectiveness of each method lies outside of the scope of this work. However, a qualitative comparison, including the advantages and disadvantages of each method, is discussed.

Project-based learning is beneficial for several reasons and the advantages depend on the context in which project-based learning is used. Evaluations indicate that students become more familiar with the design process, gain teamwork experience, develop technical writing and presentation skills, and are able to collaborate with industry professionals [14]. Students also show greater interest, increased participation, and greater depth of technical knowledge as a result of design projects. One common disadvantage is the sacrifice of some course content to allow time for project-based learning [14, 15].

A significant advantage of inquiry-based learning is the challenge presented to students to create and discover knowledge instead of simply receiving knowledge from their instructors. This method helps students develop independent, critical thinking. Inquiry-based learning can be used separately as shown by Tamir [21]. However, this method is perhaps the most effective when used in conjunction with other design integration methods such as project-based learning or design-based learning.

Design competitions are similar to project-based learning methods because students are tasked with a design project. However, design contests allow students to experience the competitive aspect of engineering, which can lead to increased motivation for the project and a greater excitement for learning. The contests expose students to the design process by providing experience in concept identification, knowledge acquisition, and exercising judgment. Students report that the contest increased their interest and was more effective for learning course material than conventional laboratory sessions [22]. One drawback of this approach is the sacrifice of depth in some course topics to allow more time to teach contest-relevant material [22]. Impromptu design contests are beneficial because they do not require as much time as semester-long design contests and focus on the application of only one or two engineering principles [24]. Students are introduced to the basic design process, decision-making, and optimization [24]. Students are also challenged to refine their skills in creative thinking, problem solving, and team building [25].

Implementing case study modules is an advantageous design integration technique because students are able to review and evaluate the decisions and mistakes of designers before them [27]. This method fosters critical thinking and enables the students to become reflective practitioners of engineering. Students view their experience with case study modules as rewarding and useful [28].

Reverse engineering is unique because it is focuses on disassembly and redesign of a product to teach the design process and reinforce engineering principles. This hands-on design integration method emphasizes reflective practice and fosters integrative design thinking [29]. Studies show that reverse engineering also contributes to increased retention rates of engineering students [29].

Design-based learning allows students to gain a better understanding of scientific concepts as a result of designing solutions to given problems. Students become more familiar with the design process, gain teamwork experience, and develop communication skills [31]. Design-based learning methods also help students understand science concepts well enough that teachers are able to move at a faster pace and cover more content in class [35, 36]. Using design to teach engineering science principles is also utilized by the reverse engineering method.

The practical design integration methods presented can be used to accomplish similar learning objectives depending on the context in which they are used. These methods can be used separately, but are perhaps more effective when used in conjunction with one another.

Conclusion

Design is fundamental to engineering education and incorporating design throughout the curriculum has become the focus of many institutions in recent years. Some institutions have revised their entire curriculum. However, this approach is not practical for every institution. Practical design integration methods that can be implemented into existing engineering courses may be more useful to institutions that are not able to completely restructure their curriculum. To assist in this effort, various design integration techniques are reviewed in this paper and include examples of project-based learning, inquiry-based learning, design competitions, case study modules, reverse engineering, and design-based learning. The methods presented in this work can be considered as a family of practical design integration methods that are related in various ways and can be used separately or together for engineering design education. A discussion of the methods qualitatively highlights the advantages and disadvantages of each method.

1. Grayson, L.P., *A Brief History of Engineering Education in the United States.* Engineering Education, 1977. **68**(3): p. 246-64.
2. Pister, K.S., *Engineering education: designing an adaptive system*. 1995: National Academies Press.
3. Dym, C.L., et al., *Engineering design : a project-based introduction*. 3rd ed. 2009, Hoboken, N.J.: John Wiley & Sons. xxi, 327 p.
4. Dutson, A.J., et al., *A Review of Literature on Teaching Engineering Design Through Project -Oriented Capstone Courses.* Journal of Engineering Education, 1997. **86**(1): p. 17-28.
5. Wilczynski, V. and S.M. Douglas, *Integrating design across the engineering curriculum: A report from the trenches.* Journal of Engineering Education, 1995. **84**(3): p. 235-240.
6. Kartam, N.A., *Integrating Design into a Civil Engineering Education.* International Journal of Engineering Education, 1998. **14**(2): p. 130-135.
7. Dym, C.L., *Learning engineering: Design, languages, and experiences*.* Journal of Engineering Education, 1999. **88**(2): p. 145-148.
8. Crawley, E.F. *Creating the CDIO syllabus, a universal template for engineering education*. in *Frontiers in Education, 2002. FIE 2002. 32nd Annual*. 2002. IEEE.
9. Mushtak Al-Atabi, A.S. and M. Al-Obaidi, *CDIO curriculum for mechanical engineering undergraduate course.* Journal of Engineering Science and Technology, 2011. **6**(2): p. 251-259.
10. McKenna, A.F., et al., *IDEA: formalizing the foundation for an engineering design education.* International Journal of Engineering Education, 2007. **22**(3): p. 671.
11. Koen, B.V., *Toward a strategy for teaching engineering design.* Journal of Engineering Education, 1994. **83**(3): p. 193-201.
12. Carroll, D.R., *Integrating design into the sophomore and junior level mechanics courses.* Journal of Engineering Education, 1997. **86**(3): p. 227-231.
13. Dym, C.L., et al., *Engineering design thinking, teaching, and learning.* Journal of Engineering Education, 2005. **94**(1): p. 103-120.
14. Libii, J.N. *Integration of Design in the First Course in Fluid Mechanics: Experience and Evaluation*.
15. Miri, S.M. and R.J. Fu, *A hands-on practical approach to teaching engineering design.* Education, IEEE Transactions on, 1993. **36**(1): p. 131-136.
16. Yoder, M.A. *Sparking Life in a Circuits Classroom*. in *Frontiers in Education Conference, 1993. Twenty-Third Annual Conference.'Engineering Education: Renewing America's Technology', Proceedings.* 1993. IEEE.
17. Hadim, H.A. and S.K. Esche. *Enhancing the engineering curriculum through project-based learning*. in *Frontiers in Education, 2002. FIE 2002. 32nd Annual*. 2002. IEEE.
18. Abu-Mulaweh, H.I. and A.A. Al-Arfaj, *Engineering design experience of an undergraduate thermodynamics course.* World Transactions on Engineering and Technology Education, 2012. **10**(1): p. 77-81.
19. Newcomer, J.L. *A design project based approach to teaching automatic control theory to mechanical engineers*. in *Frontiers in Education Conference, 1998. FIE'98. 28th Annual*. 1998. IEEE.
20. Frank, M., I. Lavy, and D. Elata, *Implementing the project-based learning approach in an academic engineering course.* International Journal of Technology and Design Education, 2003. **13**(3): p. 273-288.
21. Tamir, P., *Considering the role of invitations to inquiry in scienceteaching and in teacher education.* Journal of Science Teacher Education, 1990. **1**(3): p. 41-45.
22. Gregson, P. and T.A. Little, *Using contests to teach design to EE juniors.* Education, IEEE Transactions on, 1999. **42**(3): p. 229-232.
23. Clayton, G., N. Radlinksa, and T. Wojcik. *Integrating design education across the curriculum using impromptu design projects*. in *ASEE Mid-Atlanta Section Conference, Villanova, PA*. 2010.
24. Clayton, G., *Impromptu Design Exercises in an Introductory Mechanical Engineering Course American Society for Engineering Education. pp. 00740-12. 2012.* 2012: p. 00740-00712.
25. Reidsema, C., S. Wilson, and C. Netherton. *Impromptu design as a vehicle for developing team work and problem solving skills in design engineering*. in *International Conference on Engineering Education, Gainesville, Florida, USA*. 2004.
26. Davis, M.L. and S.J. Masten. *Design competitions: does "multidisciplinary" contribute to the team building experience?* in *Frontiers in Education Conference, 1996. FIE'96. 26th Annual Conference., Proceedings of*. 1996. IEEE.
27. Richards, L.G., et al., *Promoting active learning with cases and instructional modules.* Journal of engineering education, 1995. **84**(4): p. 375-381.

28. Gorman, M.E., et al., *Teaching Invention and Design: Multi-Disciplinary Learning Modules.* Journal of Engineering Education, 1995. **84**(2): p. 175-185.
29. Wood, K.L., et al., *Reverse engineering and redesign: Courses to incrementally and systematically teach design.* Journal of Engineering Education, 2001. **90**(3): p. 363-374.
30. Aglan, H.A. and S.F. Ali, *Hands-On Experiences: An Integral Part of Engineering Curriculum Reform.* Journal of Engineering Education, 1996. **85**(4): p. 327-330.
31. Kolodner, J.L., *Facilitating the learning of design practices: Lessons learned from an inquiry into science education.* Journal of Industrial Teacher Education, 2002. **39**(3).
32. Akins, L. and D. Burghardt. *Work in progress: Improving K-12 mathematics understanding with engineering design projects*. in *Frontiers in education conference, 36th annual*. 2006. IEEE.
33. Etkina, E. and A. Van Heuvelen, *Investigative science learning environment–A science process approach to learning physics.* Research-based reform of university physics, 2007. **1**.
34. Cantrell, P., et al., *The effects of engineering modules on student learning in middle school science classrooms.* Journal of Engineering Education, 2006. **95**(4): p. 301-309.
35. Apedoe, X.S., et al., *Bringing engineering design into high school science classrooms: The heating/cooling unit.* Journal of Science Education and Technology, 2008. **17**(5): p. 454-465.
36. Oliver, D.L. and J. Kane, *Engineering Design Modules as Physics Teaching Tools.* The Physics Teacher, 2011. **49**(4): p. 242-245.
37. Puente, S.M.G., M. van Eijck, and W. Jochems, *A sampled literature review of design-based learning approaches: a search for key characteristics.* International Journal of Technology and Design Education, 2013. **23**(3): p. 717-732.