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Introduction of a Design-Build-Fly Project into Aerospace Systems Engineering Course

Kevin Massey
RMIT University
Corresponding Author Email: kevin.massey@rmit.edu.au

BACKGROUND
A second year Systems Engineering course taught at RMIT University in Melbourne Australia is described. Some particular challenges of this course are described which include the varied educational background of the international cohort of students and the abstract nature of systems engineering relative to other engineering topics. The introduction of a Design, Build, Fly component into the course was introduced in order to improve the ability of the students to grasp the system engineering concepts, which were considered abstract by students in previous years. This effort is similar in nature to Conceive, Design, Implement, Operate (CDIO) course structure, however it is atypical in that it is delivered to second year engineering students.

PURPOSE
It was hypothesized that the introduction of a Project Based Learning (PBL) component into a second year design course could both improve the student satisfaction level and improve the learning outcomes of the students.

DESIGN/METHOD
The introduction of a Design, Build, Fly (DBF) component (a type of PBL) was introduced into a second year Systems Engineering course. Data provided from student responses to course surveys across three years were used to assess changes in student satisfaction, their ability to handle unfamiliar tasks, and their perception of whether the course would help them in the workplace. Written feedback to the instructor was also examined. The progress of students through the course in terms of their performance on a similar task was also examined. The data set encompassed a year when there was no DBF component, a DBF component, and an integrated DBF component which enables the examination of the effectiveness of adding the DBF.

RESULTS
The inclusion of the PBL component resulted in improved student satisfaction scores. Further, tighter integration of the DBF component with the course content resulted in even higher student satisfaction and improved learning outcomes. Excerpts from student reflections on the course indicate that they have a better appreciation for the systems engineering process.

CONCLUSIONS
It is shown that the DBF greatly improved student satisfaction, and better enabled the students to understand the relevance of systems engineering and contextualize the course material. A number of challenges are noted in the course development and delivery, and lessons learned from the delivery of the course and the DBF component are provided.

KEYWORDS
Systems Engineering, Design Build Fly, Aerospace Engineering, CDIO, Project Based Learning

Introduction

Systems engineering education comes in many different forms from professional short courses, to single courses in universities, to degree programs. There are also many professionals who learn the ins and outs of systems engineering via on the job training. Sage (2000) does an excellent job of providing a high level overview of the systems engineering process and describing how to translate these concepts into practice through education. At the highest level systems engineering can be described a set of tools or a framework which allows customers' desires or requirements to be efficiently communicated to designers, engineers, maintainers, etc. who realize and implement the system at its end state. This paper describes a systems engineering course offered to Aerospace Engineering students at a leading Australian University which has many features that, when combined, provide a rare set of conditions and thus likely a unique course on systems engineering. The insights and lessons learned from this course are described below.

Prior Work

There are numerous texts on how to teach systems engineering, and this work does not pretend to offer the 'best' way to teach systems engineering. (And there may be no best way.) A comparison of many different system engineering programs is provided by Brown and Scherer (2000). In their paper they attempt to categorize the different system engineering degree programs offered in the United States. Asbjornsen and Hamann (2000) argue that systems engineering is best taught when it is multidisciplinary in nature and thus should be integrated across all engineering disciplines. Shimazu and Ohkami (2011) describe a graduate systems engineering course in Japan which uses project based learning based on the iRobot Roomba platform. Similar to the observations reported below, they observed that students had a tendency towards moving directly into problem solving without considering systems engineering principles. Another instance of a student project incorporated into a Master's curriculum is that of a CanSat program in the SpaceMaster program (Schilling 2006). Schilling describes the importance of hands-on system design in teaching the concepts of system engineering via the CanSat development undertaken by the students.

Project Based Learning (PBL) is an educational technique whereby students have the concepts taught in a course reinforced by completing a project. There are numerous examples of courses and methodologies which include PBL elements and this paper is not intended to review all of these examples. Carlson and Sullivan (1999) describe a program which has been in existence since 1997 and attempts to integrate project based learning across all engineering disciplines. Dym et al (2005), provide a useful reference on PBL and make the interesting distinction between first year 'cornerstone' projects and the more common final year capstone projects. The cornerstone projects were described as projects early in the engineering curriculum which were used to help the students obtain a better feel for what engineers actually do, and in that sense, the course described below could be described as a cornerstone course.

Specific to Aerospace engineering there are a few notable examples of PBL which typically take the form of Design Build Fly (DBF) projects. Brodeur et al. (2002) describe a PBL approach at MIT in which the students designed, built and flew lighter than air vehicles. The authors conducted student surveys which indicated that courses with PBL approaches consistently had a higher level of student satisfaction. Similar to the course described here, Young et al. (2003) describes a 2nd year engineering course at MIT which implemented a DBF component. The authors describe how the course evolved over several years and now is an important part of the MIT conceive-design-implement-operate (CDIO) educational strategy. Finally, Crawley et al. (2011) describe a NASA and industry sponsored effort which indicated the importance of incorporating the CDIO strategy into aerospace curricula. It was concluded that the inclusion of DBF projects into aerospace engineering courses was crucial to properly educate the future workforce.

Overview of Course

RMIT University is a multicampus university with 75,000 students with the majority of these students located in Melbourne Australia. Due to Australia's location in the Pacific region and the fact that Australian universities provide degrees with programs taught in English, there are a large number of international students from the region. Aerospace Engineering, which perhaps has been more dominated by English speaking corporations and institutions than other engineering disciplines, is a degree that is often considered more valuable when graduating from a degree program delivered in English. The typical Aerospace Engineering cohort at RMIT University consists roughly of 50% Australian citizens, 25% Chinese, and large contingents from India, the Middle East, and other south east Asian countries. Roughly half of the students in the systems engineering courses received their prior education in a language other than English and often using an educational style that is not typical to Western teaching methodologies. This multiculturalism creates challenges in many courses and these challenges are made more difficult in a course such as systems engineering where a major portion of the course revolves around methods of communication and processes for engineering large and complex projects.

The systems engineering course in the Aerospace Engineering program is delivered to second year students at RMIT University. Systems engineering courses are considered by most to be high level courses that are usually taught to fourth year students or even in graduate programs, and it was this author's opinion, when he first undertook the teaching of this course, that it should be a 4th year (or later) course. Developing and delivering a systems engineering course to second year aerospace students, requires some rethinking of the course material and methods used for delivery. For example, it is not feasible to ask the students to do detailed trade space analysis on an aircraft when they have yet to have courses on performance, propulsion, or even compressible flow. On the other hand, it is possible utilise other examples for which the students are familiar such as mobile phones. Systems engineering is often thought of as a 'synthesis' course where students pull together knowledge from many other courses similar to a capstone design course. However, if the basic tenets of system engineering are taught effectively, it provides a framework for students to take a more holistic view of their subsequent academic courses.

The final element which makes the course at RMIT University rather unique, is that it also incorporates a design, build, fly (DBF) element into the course. The DBF element has proved a useful method for students to get first-hand knowledge of how a systems engineering process can improve the design and fabrication of a product (in this case a small radio controlled aircraft).

The combination of a multicultural cadre of students, inexperienced engineers, and the DBF experience results in a course which has a unique environment for educating early career aerospace students in the art of systems engineering.

Design, Build, Fly

In this course, the students were placed into groups of 6-7 students and tasked with transforming a set of requirements into a small radio controlled aircraft. The design was left somewhat open ended in order to allow the students a degree of creativity, but their choices of hardware were limited in order to make the problem tractable such that it can be completed in the span of one semester. Typically an element of fun is added such as the requirement to fly as many M&Ms for as long as possible, where their final score is in part based on MM-s (or the number of M&Ms flown on the aircraft times the flight duration, 2011). In 2012, the mission was modified such that the students were tasked with dropping toy paratroopers onto a target.

The student groups are tasked with delivering a Preliminary Design Review (PDR) of their concept to the instructor in order to assess whether they have understood and articulated the requirements and constraints on the design and to assess whether they have a viable concept. The students must pass the PDR before moving to the next phase of the program which illustrates the importance of getting the requirements right. Once they pass the PDR, they are then tasked with delivering a Critical Design Review (CDR). During the CDR, their more detailed design is critically assessed and the groups are offered advice on how to further improve their design and to improve their proposed manufacturing process. Their design is assessed with respect to whether it is likely to satisfy the mission requirements, and their report is judged on its effectiveness at detailing the design. Only when they pass the CDR, are they finally given the materials and components to begin fabrication of their aircraft. This process eliminates the problem described by Shimazu and Ohkami (2011) and drives home the key systems engineering point of getting the design right before the start of manufacturing. The students are also provided an opportunity to participate in a practice flight session where their aircraft's performance is initially evaluated. This provides them with opportunities to make further modifications before the day of the fly off and serves to illustrate another key concept in systems engineering which is the importance of test and evaluation. During the fly off, the performance of their aircraft is assessed against the mission requirements. Of course there is competition amongst the groups to see who has the highest score (in terms of MM-s or paratroopers on target), but the total score of their DBF aircraft performance is also based on other aspects such as flying qualities, and controllability. Figures 1 through 3 show some images of the student built aircraft in action near or over the dropzone and releasing plastic paratroopers.

The DBF experience complements the curriculum by reinforcing the importance of design reviews, understanding requirements, and proper communication. The students are also provided feedback in terms of a grade at four points during the project. Their total DBF grade is based on the PDR grade, CDR grade, fly off score, and final report grade, all in equal measure. It also provides the students with an experiential learning opportunity to directly participate in a systems engineering process with benefits described below.

Figure 1: Aircraft approaching the drop zone.

Figure 2: Aircraft releasing paratroopers.

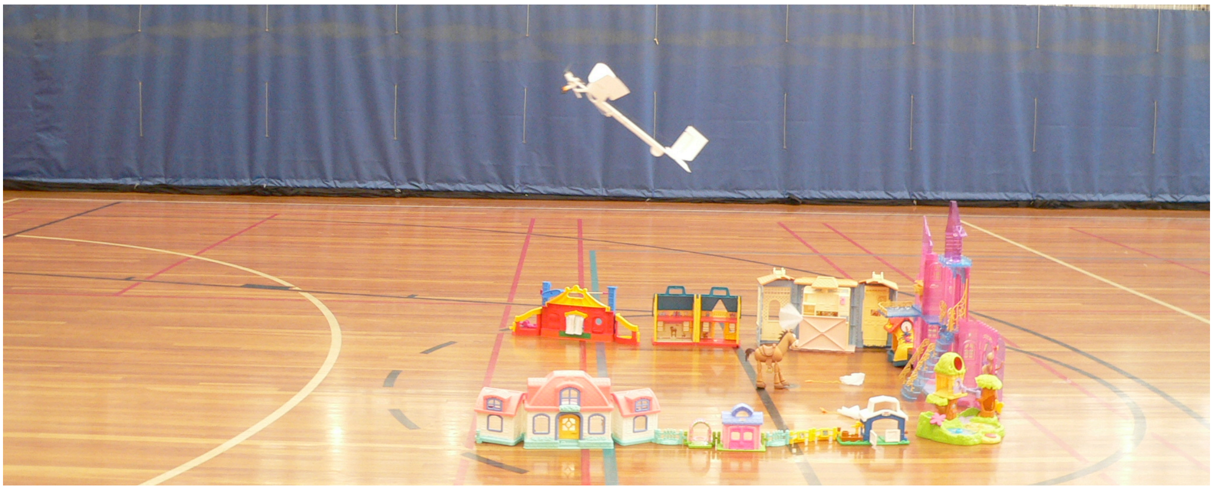

Figure 3: Aircraft at high angle of attack over dropzone.

Observations and Student Feedback

From an instructor's point of view there are several observations which can be made that would aid others in attempting a similar delivery. The abstract nature of Systems Engineering, by that I refer to a topic whereby the students cannot solve a problem and come up with an exact numerical answer, poses a challenge in terms of assessment of the students' understanding. It also makes it more challenging for the students to remain engaged as they have difficulty in grasping why they should be learning these concepts. The introduction of the DBF project and the students' use of techniques and processes taught during the course to deliver a tangible end product (in terms of a flying aircraft) has led to increased course satisfaction. Student satisfaction in the course as measured by an University run survey (where students answer questions in an anonymous fashion without the instructor in the room) and compiled as an aggregate of 6 questions, rose from 20% in 2009 when there was no DBF component, to 50% when the DBF was first introduced in 2010, to nearly 80% in 2011, when the DBF was fully integrated into the curriculum. (In 2010, the DBF was introduced as part of the assessment without changing the curriculum, while in 2011 the course was restructured such that course topics tied directly into the project.) Each survey was examined to insure that it had a significant number of respondents to be statistically meaningful. The response rate varied from 31% to 82%, however it should be noted that the highest response rate corresponded to the smallest class and vice versa.

Examining the survey results in greater detail reveals an important distinction. When the students were asked whether the course helped them to tackle unfamiliar problems, it was found that the mere introduction of an additional DBF component only affected a modest improvement. But, when the DBF was integrated into the course such that the lectures and assignments directly tied into the project, the students felt that the course was much better at building their confidence in dealing with new types of problems as shown in Figure 4. When the students were asked whether they felt the course would help them in their future workplace, the improvement in response was similar. As shown in Figure 5, there was an only modest increase in the students' response with the introduction of the DBF, but a much improved response when the systems engineering concepts where tied more directly with the DBF exercise. Thus an important distinction can be made. While the introduction of the DBF led to an improvement in the students' satisfaction with the course, it only modestly improved their (perceived) learning outcomes. When the project was more closely tied to the curriculum, then the student satisfaction was further improved, but more importantly they were more confident in tackling new problems and felt they were better prepared to enter the workforce.

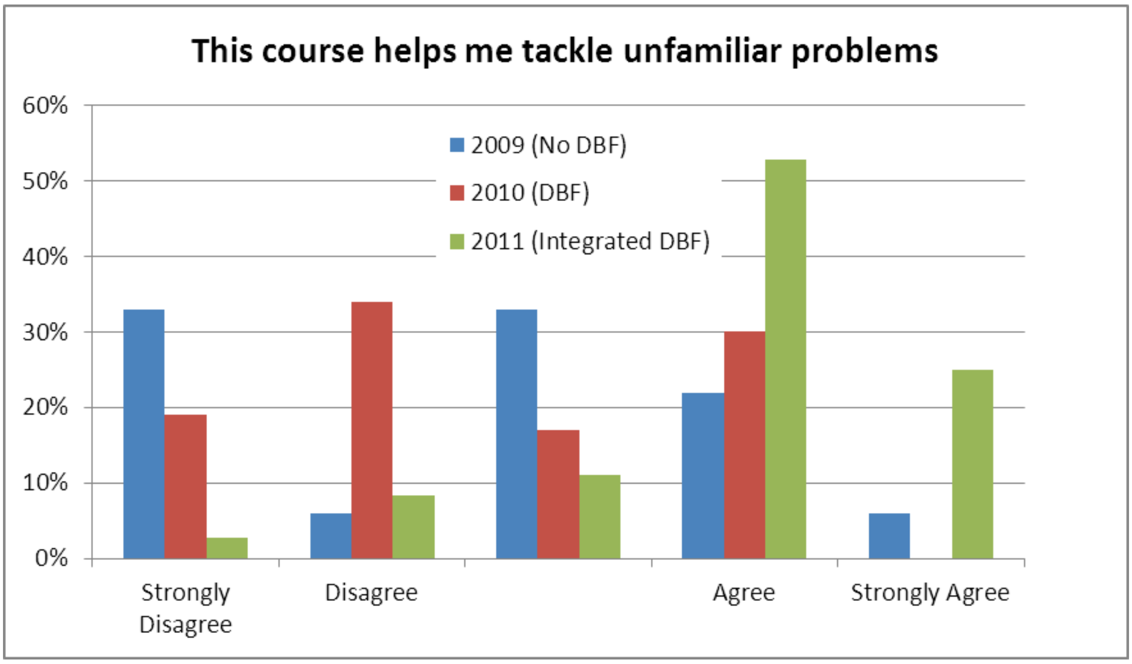

Figure 4: Improvement in students' ability to tackle unfamiliar problems.

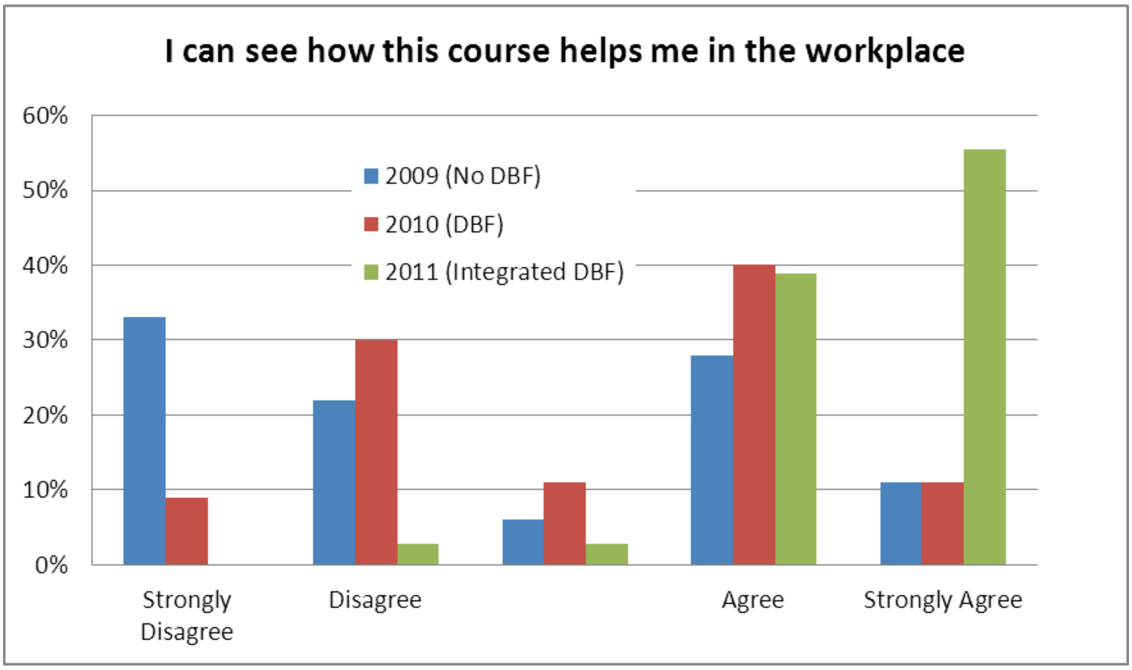

Figure 5: Improvement in students' perception of whether course would help in their career.

It was also observed that as a whole the students initially performed poorly on the PDR. The two root causes for this were the fact that the students resented the fact that they were not allowed to start construction on their DBF aircraft before doing the PDR, and that they failed to grasp the importance of understanding and communicating the requirements via a conceptual design. It has been consistently found that the students dramatically improve their performance on the CDR which is an indicator that some learning has occurred. The CDR was a similar, but harder task than the PDR, yet the average grade increased 10 points (out of 100) or one letter grade in 2011 and roughly 5 points in 2012. The feedback provided during the PDR, and perhaps the poor grades, appears to communicate to the students the importance of the systems engineering process early in a project lifecycle which is a key learning outcome in systems engineering. It should also be noted that it is typical to see further improvements on the final report which is indicative that the learning process continues throughout the semester. Thus while the initial student resentment and disappointment at poor performance can be frustrating, a modicum of patience results in improved understanding, improved performance, and at the end, joy as the students successfully fly their aircraft and complete the mission.

The final set of observations revolve around the challenges associated with group projects. Group projects are an excellent educational tool for preparing students to enter into workforce where the majority of careers will see the graduates working as part of a team. Group projects also allow for larger scale projects, such as the DBF, to be completed in a single semester. However, providing individual assessments for the participants in the group is quite challenging. It is important to ensure that students who do not contribute to the group do not receive as high of a grade as those who are carrying the group. It is important to communicate this early and often and in a measurable way such that the poorly performing students know they are not contributing and that their grade will subsequently suffer. Many students, particularly early in their career, are not effective at communicating this to their fellow group members and thus it is an important for the instructor to inform the non performing students of the consequences. In most cases the instructor will not be working closely enough with individual groups to fully assess individual contributions thus using peer assessments is an important tool. Peer assessments should address multiple performance metrics and should happen both at the early stages of the project and at the end of the project. In 2012, the systems engineering students completed peer assessments through using collaborative forms via the Google Docs platform. These peer assessments were done after the PDR, after the CDR, and at the end of the project. Both the PDR and CDR reviews were used in the feedback session with the instructor and were used to identify groups with problems and individuals who were not performing. The entire set of peer assessments were used to scale the team DBF grade to provide individual grades based on individual performance.

With respect to the feedback provided by students taking this course, it is largely positive. There were complaints that the project was not as heavily weighted as it should have been relative to the level of the effort. While there is some merit in the above complaint, it is difficult to provide individual grades on group projects and thus heavily weighting the group project makes determining overall individual grades for the course even more difficult. Further, it is not acceptable to have an individual pass a course merely because by the luck of the draw he/she was on an excellent team, when said person performed exceedingly poorly in the other course assessments. A project weighting of roughly 30% of the overall course appears to strike an appropriate balance. Most students did see the value in the design reviews by the end of the course, but a handful continued to hold the belief that they would have performed better by allowing them to start their construction on day one of the semester. While it may be true that aircraft with similar performance could be built by trial and error, that does not reflect the reality of modern product design cycles, and misses the point of the system engineering process.

By the end of the course most students realized the value of the course and the systems engineering process. The author believes that the DBF effort was instrumental in achieving this objective, and this is borne out by the responses from a number of groups. There were several groups who performed quite poorly on the PDR but who wound up with very successful aircraft and excellent technical reports.

The following are excerpts from student reflections on the course.

We think systems engineering really helped us with the planning process. There was a lot of stuff we did because it was required for the PDR or CDR that some of us would not have considered, but it came in handy later on. Now we understand that if it hasn't been planned out properly, and clearly thought through, every step of the way, you waste a lot of time deciding how you're going to do something, and sometimes materials too. If this had been a major industry project, it could have added up to a lot of money and potentially months of redesign… - µAir

We have learnt that by providing detailed design considerations before manufacturing, we could have saved a lot of time and effort to manufacturing. Overall, systems engineering has given us new ways to solve problems. – Team F.O.B.

The systems engineering processes provided us with a general guideline to designing and manufacturing a complete system. They provided us with a logical design sequence, and gave us a rough timeline and the reviews provided us with vital feedback on our design. With each step in the systems engineering process our design improved as well as getting more detailed. – Team Airboss

The Systems Engineering Process helped tremendously as we achieved a design that was though about conceptually and theoretically and not just from the design point of view and built straight away. It allowed the team to focus on different stages of the design process so *we did not rush into the building part. The feedback from our PDR, CDR and discussions … helped majorly in the development of our MAV. It helped us understand what actual people do in order to receive a contract from a company. Finally, because we performed so well in the flights (highest MM-s) we have a greater appreciation for the systems engineering process. – The Inviscid Initiative*

In conclusion, the introduction of a DBF into a 2nd year systems engineering course has proved to be highly successful. The student satisfaction has been greatly improved and the students have a better understanding of not only the system engineering principles, but perhaps more importantly, why systems engineering is important. Further, it was found that it was necessary to integrate the project with the course material to fully realize the benefit of the DBF in terms of student outcomes.

References

Asbjornsen, O.A. and Hamman, R.J., "Toward a Unified Systems Engineering Education," IEEE Transactions on system, Man, and Cybernetics – Part C: Application and Reviews, VOL. 30, NO. 2, MAY 2000, pp. 175 – 182.

Brown, D.E. and Scherer, W.T., "A Comparison of Systems Engineering Programs in the United States," IEEE Transactions on system, Man, and Cybernetics – Part C: Application and Reviews, VOL. 30, NO. 2, MAY 2000, pp. 204 – 212.

Brodeur, D.R., Young, P.W. and Blair, K.B., "Problem-Based Learning in Aerospace Engineering Education," Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education, 2002.

Carlson, L.E. and Sullivan, J.F., "Hands-on Engineering: Learning by Doing in the Integrated Teaching and Learning Program," *International Journal of Engineering Education*. Vol. 15, No. 1, 1999, pp. 20-31.

Crawley, E., Niewoehner, R., Gray, P. and Koster, J., "North American Aerospace Project - Adaptable Design/Build Projects for Aerospace Education," Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, June 20 - 23, 2011.

Dym, C.L., Agogino, A.M., Eris, O., Frey, D.D. and Leifer, L.J., "Engineering Design Thinking, Teaching, and Learning" Journal of Engineering Education, January 2005, pp. 103 – 120.

Sage, A.P., "Systems Engineering Education," IEEE Transactions on system, Man, and Cybernetics – Part C: Application and Reviews, VOL. 30, NO. 2, May 2000, pp. 164 – 174.

Schilling, K., "Design of Pico-Satellites for Education in Systems Engineering," *IEEE* Aerospace & Electronic *Systems Magazine, July 2006, pp. S9 – S14.*

Shimazu, K. and Ohkami, Y., "Systems Engineering Education for Inexperienced Students by Providing Hand-on Practices." Systems Conference (SysCon), 2011 IEEE International, pp. 367 – 370.

Young, P.W., de Weck, O.L. and Coleman, C.P., "Design and Implementation of an Aeronautical Design-Build-Fly Course," Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition , American Society for Engineering Education, 2003.