AC 2007-2223: DEVELOPMENT OF A LEARNING-FOCUSED CORE ASTRONAUTICS COURSE

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Lynnane George earned her commission in the Air Force from ROTC at the Georgia Institute of Technology in 1988 with a BS degree in Mechanical Engineering and MSME from Ga Tech in 1989. She began her Air Force career in the Defense Satellite Communication Program Office at

Los Angeles AFB, California where she served in the Mechanical Engineering Branch. She was then selected for a one-year Education with Industry program with the Aerospace Corporation, where she performed launch vehicle vibrations and launch wind loads analyses. She then moved on to the Titan System Program Office where she was the Flight Loads and Dynamics Manager for two years before moving to a mission management position. As mission manager for the Titan IV/Centaur mission TIV-23, she was responsible for all integration, planning, technical analysis, mission specific hardware design and procurement, contracting actions, launch readiness, and launch operations for the launch. TIV-23 was launched successfully from Cape Canaveral on 14 May 1995. She next moved to the US Air Force Academy in 1995, where she served as an instructor and later professor of astronautics as well as Director of Research. She then returned to Georgia Tech to pursue her PhD in Mechanical Engineering and completed her research dissertation "Active Vibration Control of a Flexible Base Manipulator" and degree in 2002. She next moved to the Air Force Research Laboratory's Space Vehicles Directorate at Kirtland Air Force Base, New Mexico. At Kirtland, she led a 90 person branch performing research in six spacecraft technology areas. She also served as Acquisition Command Trainer and Mentor in the Office of Military Cooperation in Afghanistan for a five month period before returning to the US Air Force Academy in 2005.

EDUCATION:

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Development of a Learning-Focused Core Astronautics Course

Abstract

A new undergraduate core course in astronautical engineering was developed at the US Air Force Academy (USAFA) in 2004. This followed an extensive review of two undergraduate core astronautics courses. The review included two small focus groups and student written assessments from approximately 700 students. Anonymous time logs from every student in the two courses provided a quantitative determination of the amount of time students spent working outside of class. To determine if students had an adequate understanding of space, current and former faculty were surveyed along with space leaders in the Air Force who supervise Academy graduates. As a result of this broad review, it was decided that the two courses should be combined into one large, improved course, which is now taught to approximately 1,000 cadets each year. This new course was redesigned with an emphasis on student learning. Computerized visual animation tools were added to the course, which allowed students to see satellite orbits. These computer-based labs emphasized key concepts from class such as satellite maneuvering, ground tracks, rendezvous, orbit propagation, perturbations, and constellation design. A small table-top satellite, with fully functional subsystems, was also used to demonstrate and reinforce satellite design principles introduced in the text. These principles were then applied to a preliminary satellite design project. New assessment methods using on-line quizzes measured student learning for every lesson. These on-line quizzes required students to prepare for every class. Multiple assessments conducted after the initial offering of this new course showed students were much better prepared for class. Many of the new methods used in this course have since been adapted by other courses, including some courses from other disciplines, with very favorable results.

Background

In the fall of 2003, the Air Force Academy's department of Astronautics began a major review of two undergraduate core astronautics courses. These courses, which had been taught for over 15 years, covered basic principles of astrodynamics including: two-body orbital mechanics, Kepler's problem, Hohmann transfers, rendezvous, and interplanetary transfers. The courses also covered rocket propulsion, staging, and launch windows. In addition, about a third of each course was spent covering satellite design, including an overview of payloads and major satellite subsystems. Every cadet at USAFA was required to take one of these two courses. Individual departments decided which course their majors were required to take. One of these courses was taught to approximately 500 students each year, and the other was taught to about 300 students a year.

The smaller course, Astro 320, was more technical and designed for engineering majors and most science majors. It included computer programming projects, which followed some of the astrodynamics topics including converting a satellite's position and velocity vectors to classical orbital elements and propagating them forward in time. The larger course, Astro 410, did not have any computer programming. The students in this course were typically non-technical majors.

Course Reviews

A committee of five experienced instructors was formed to review these two courses and recommend any necessary changes. The committee gathered data from the students, current and former faculty, and senior military leaders in space related career fields.

Student input came in many forms, all of which were completely anonymous. For over 20 years, students had submitted end-of-course critiques on every course at the Air Force Academy. These included standardized Scantron questions as well as written comments. Questions focused on the instructor's ability and the course material covered. They also asked questions about timeliness of feedback and usefulness of the course text. These critiques allowed faculty to compare different courses and detect trends in student perceptions. The committee reviewed recent critiques from both astronautics courses and decided more input was needed from the students.

Therefore, the committee solicited the help from the Air Force Academy's Center for Educational Excellence (CEE), which occasionally runs student focus groups for department reviews. This office conducted two focus groups at the end of the semester, one for each astronautics course. Both groups consisted of 12-15 students, comprised of a cross-section from each course. The committee provided open-ended questions, which generated discussions about the specific courses. No one from the department of Astronautics was present during these focus group discussions. Instead, the committee was given an anonymous written transcript of the discussions, which masked the students' identities. The CEE office also summarized what they thought were the strengths and weaknesses of both courses from the students' perspective. For Astro 320, the more technical course, they concluded students gained a good basic understanding of astronautics and how it would relate to their future jobs. However, students felt they had too much homework, particularly too much computer programming, which detracted from the rest of the course. For Astro 410, the non-programming course, students really liked their instructors and the course text, but they wanted feedback from their instructors on a more regular basis, and they did not see the correlation between the course objectives, the text, and the exam questions.

The committee was concerned about the level of work required by each course. Most instructors agreed Astro 320 required significantly more work than Astro 410, primarily due to the computer programming. Also, students in Astro 410 routinely came to class without doing any work outside of class. Therefore, it was understandable that they did not see a correlation between the course objectives, the text, and the exams. To quantify this data, the committee decided each instructor would collect anonymous time logs of every student from one of their classes each lesson to determine how much time students spent preparing for class. These time logs included almost 70% of the students from both courses. The time logs confirmed the committee's suspicions. Cadets in Astro 320, the more technical course, spent almost an hour more preparing for every lesson than the students in the non-programming course. The committee also discovered most students in Astro 410 did no work outside of class unless there was a test or project due the next lesson. Sometimes this meant little or no work was accomplished outside class for several weeks at a time.

In addition to gathering data from students, the committee sent surveys to current and former instructors as well as commanders from Air Force labs. The survey focused on what subjects Air Force Academy graduates understood well and what areas needed more focus. There were a variety of answers, but the general consensus was that Academy graduates understood space very well. Some people felt the course should include more discussion of specific topics: more communications, more about the space environment, etc. However, there was no real consistency in their answers. The only common theme was summarized by a senior space leader who said that the committee should resist the tendency to make a laundry list of competencies linked to the space business. He argued that the committee should "not be in the business of giving graduates just what they 'need to know about space' … the undergrad business is much more about teaching them how to learn, which means setting the 'bar' much higher than any of them will ever believe that they need to know".[1]

The committee also interviewed course directors from two other core courses at USAFA. One of these courses had historically been evaluated by students near the top of the core engineering courses. The other course, offered by the Law department, had been consistently ranked as the top overall core course at USAFA. Surprisingly, the "model" engineering course had similar issues as Astro 410 – students rarely opened the book outside of class, and faculty tended to "spoon feed" the students so they would learn the material. In contrast the Law course fostered an environment where the students had to come to class prepared. They accomplished this by grading student preparation. This was much more of the learning-focused environment the committee wanted in the astronautics course.

Redesigned Course

As a result of the semester-long review, the committee made a number of recommendations, all of which were implemented. First, the two courses were combined into one core course. The new core course, Astro 310, had a number of significant changes, which required a great deal of work from every instructor in the department. The three major changes are explained below. In addition to these changes a separate pass/fail lab was added introduce students to the programming aspect of astrodynamics.

On-line Quizzes

The course textbook, Understanding Space, by Sellers, was always rated very high by the student critiques. It is extremely easy to read, and many concepts do not require additional explanation from the instructor. Unfortunately, students often did not open their book outside of class. The committee knew students would learn more if they were required to work before coming to class every lesson, not just the night before a test. Therefore, the committee recommended adding on-line quizzes which would be due before nearly every lesson. These multiple-choice quizzes were designed to take about 30 to 45 minutes each. The quizzes typically have about eight to ten questions, about half of which test very basic concepts or definitions needed for the day's lesson. The answers for these questions come directly from the textbook. The other questions are more difficult, requiring students to apply what they learned during the previous lesson.

For example, a quiz prior to the initial lesson introducing classical orbital elements might ask "What does the semi-major axis of an orbit measure?" This basic definition is covered in the assigned reading and is something every instructor would expect students to learn on their own before coming to class. In contrast, the following lesson's quiz, might ask a student to calculate the semi-major axis, duplicating the type of problem that would have been covered in class during the previous lesson.

To avoid wasting precious class time, these quizzes are taken by students on-line prior to coming to class. They are assigned for almost every lesson (37 of the 40 lessons). The quizzes are individual effort, requiring each student to work independently. Each quiz is worth less than 0.5% of their total grade, yet all the quizzes combined are worth 15% of their overall grade.

Satellite Tool Kit® (STK)

The review committee decided the course should include more software programs that help students visualize the concepts discussed in class. "Satellite Took Kit" (STK) seemed like the perfect program. Some of the department's major's courses used STK, and the committee was able to obtain an educational license for the core course as well. This is an extremely powerful, industry-standard, satellite program. It allows students to see ground tracks and 3-D orbits, reinforcing difficult principles taught in class. The committee recommended nine lessons be devoted to self-paced STK labs, which were developed by Department of Astronautics faculty specifically for this new course. These labs wrapped up each block and reinforced such topics as ground tracks, rendezvous, orbit prediction, launch windows, reentry, and constellation design.

Each of these self-paced labs now includes a 5 to 15 page lab manual, which begins by motivating the problem with real satellite systems. The students, in teams of two, are then given a problem, similar to something covered in class. After completing their calculations, the manual steps the students through the STK program, showing them how to build or modify a scenario, which allows them to visually verify the result of their calculations (See Figure 1 and 2). The goal of these labs is not to teach the students to become STK experts, but merely to allow them to visually see orbits and ground tracks, thus giving them a better understanding of more difficult concepts introduced in class.

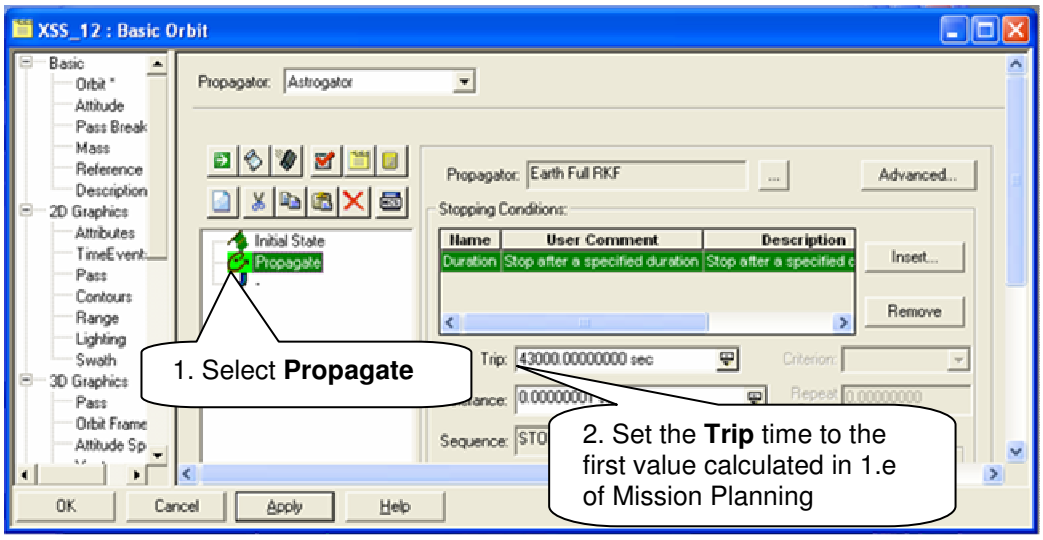

Figure 1: Sample instructions from an STK lab[2]

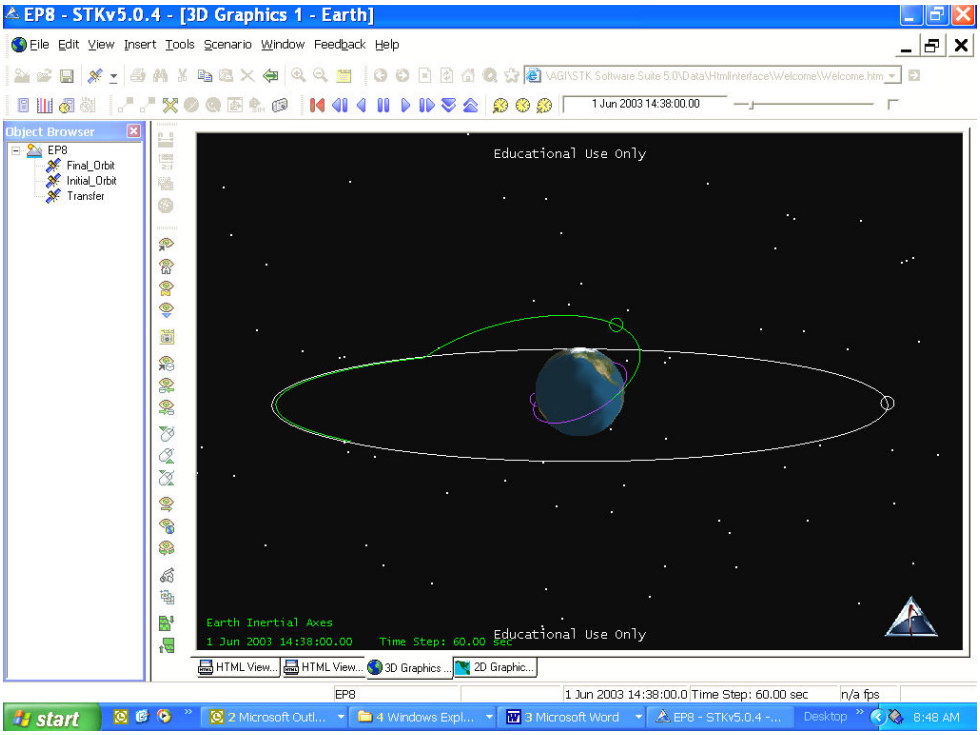

Figure 2: STK 3-D image of a combined plane change

Satellite Demonstrator

The committee also wanted more hands-on activities during the satellite design portion of the course. The Department of Astronautics had the perfect satellite demonstrator to do this. EyasSat is an educational satellite system, developed by the Department of Astronautics to help teach systems engineering. This is a complete working satellite system for classroom use. The Academy instructors, who developed this table-top satellite, received the prestigious

International Boyer Award for Teaching and Technology Excellence. This satellite had primarily been used in the Department of Astronautics' junior-level systems engineering course. The committee thought it could also be used effectively in the core course.

EyasSat can effectively demonstrate six traditional satellite subsystems, all of which are covered in the core astronautics course: Structural, Electrical Power, Data Handling, Communications, Attitude Determination and Control, and Thermal. Each subsystem is capable of receiving commands and generating telemetry via the graphical user interface (GUI). The GUI resides on laptop computers that can communicate through a wireless radio connection.[3] Figure 2 shows EyasSat's GUI for the Electrical Power subsystem.

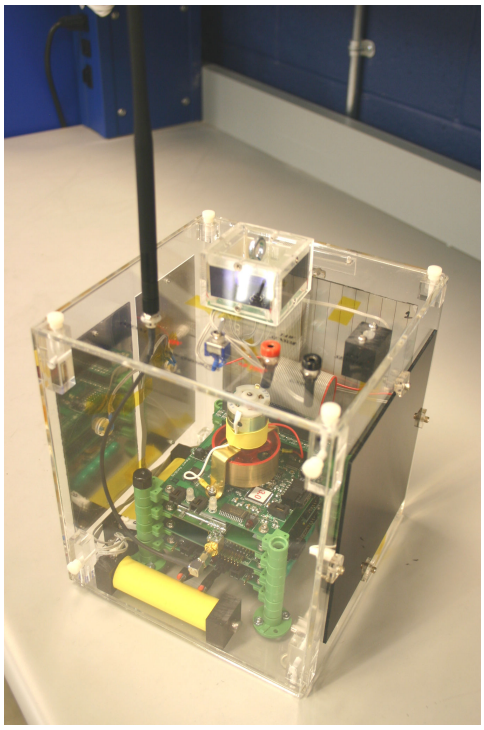

Figure 3: EyasSat[3]

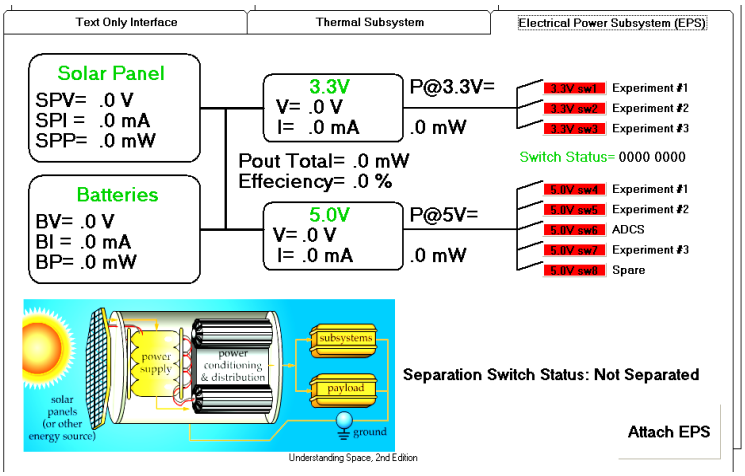

Figure 4: EyasSat's Electrical Power GUI[3]

The complete satellite measures 20x20x25 cm and weighs approximately 2.3 kg, making it easy to transport between the laboratory and the classroom. It was designed to be taken apart and reassembled many times. This has enabled over 1,700 students around the world to experience EyasSat each year.[3] The committee decided this would also be a great hands-on tool to demonstrate key satellite systems in the new core course.

Assessment of New Course

Through great effort by every instructor in the Department of Astronautics, the new astronautics course was offered one year after beginning the assessment process. Approximately 800 students took the new course in Academic Year 04-05. The Department of Astronautics assessed this new course in a number of ways. Student end-of-course critiques were collected, and the Academy's Center for Educational Excellence conducted another focus group at the end of the first semester including a cross section of cadets from the new course. In addition, anonymous

time logs were collected from students enrolled in the course during the first semester, as had been done with the two previous core courses. These data points allowed faculty to compare student perception and work effort before and after the new course was developed.

The committee found that students enjoyed the hands-on STK labs quite a bit, but they were very frustrated by the on-line quizzes. In an effort to get the course up and running, the department did not do a good job checking every on-line question, and some of the questions were much more difficult than desired. Therefore, during the second semester, instructors rewrote all the on-line questions and had two experienced instructors check every question. The course surveys after this second semester indicated the problems were corrected. There were far fewer complaints about the quiz questions, and many students commented that it kept them in the book a little each lesson.

The assessment committee was extremely pleased with the time logs from the new course. They showed almost every student did some work before every class. Students in the new course spent 40% more time preparing for class compared with the larger of the two previous core courses, Astro 410. This allowed instructors to begin class without reviewing basic concepts, which were explained in the textbook.

The Department of Astronautics also found the on-line quizzes allowed instructors to quickly focus on subjects that needed extra review. For example, an instructor can now review how his/her class did on that day's quiz before going to class. If a large number of students missed a particular question, the instructor can begin class by reviewing that problem. For example, as shown in Figure 5, an instructor can view the answers from any one student, or he/she can look at the very bottom for a summary. In this case, notice 9 of the 22 students missed the last question. This would be a good problem for the instructor to review at the beginning of class.

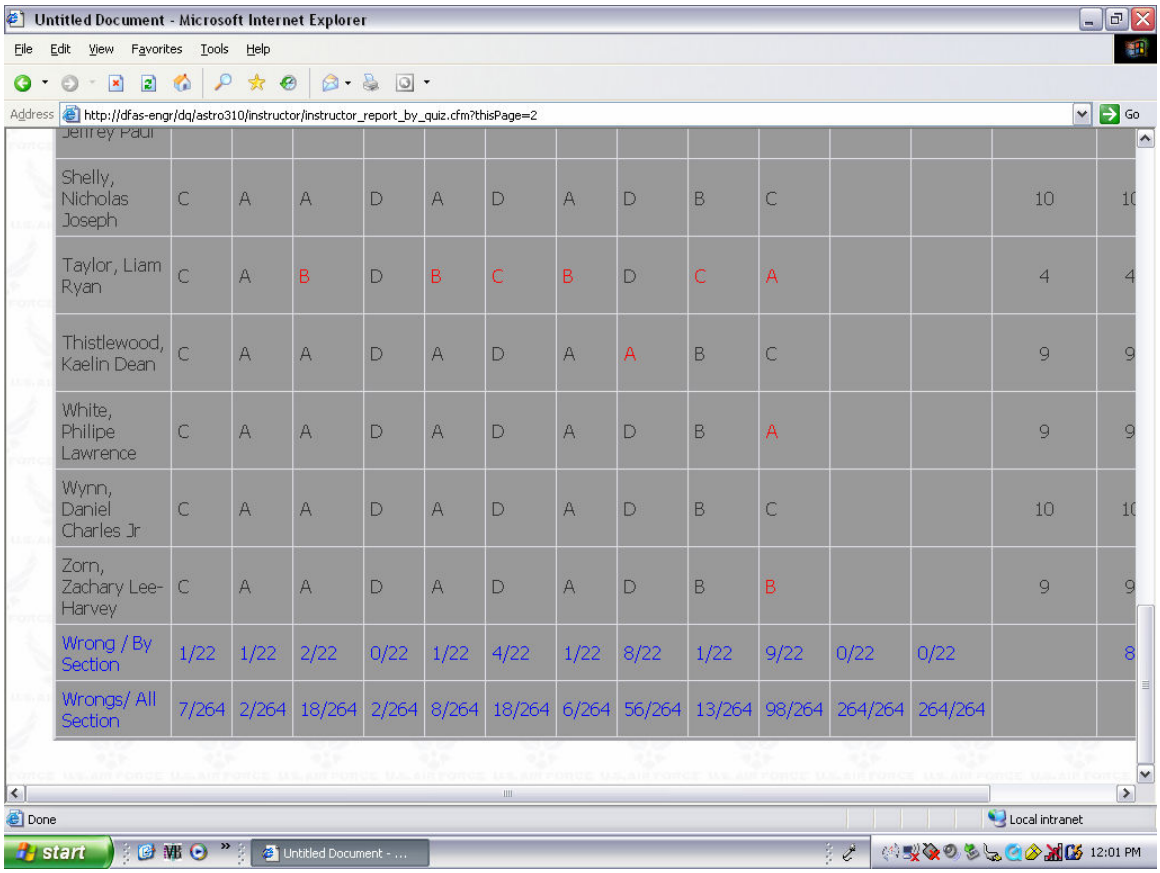

Figure 5: Instructor's summary from an on-line quiz[4]

Conclusion

An extensive review was conducted of two large core astronautics courses. This review looked at student perceptions and the amount of required work. The review committee also reviewed other core courses at the Air Force Academy, including one course from engineering and one from Law. In addition, the committee solicited inputs from current and former faculty as well as Air Force space leaders.

The committee recommended that the two courses should be combined into one larger core course, which would be required for every cadet at USAFA. There were three significant changes recommended for this new course. The new course implemented on-line quizzes almost every lesson, and a number of software labs and satellite demonstrations were added to the course. Student and instructor assessments indicated these changes improved student learning. In the new course, the average student spent more time outside of class and came to class more prepared than before. The changes have also allowed instructors to more quickly focus on areas that require review.

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