GET 'EM WHILE THEY'RE YOUNG!
Integrated Engineering for Freshmen

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Abstract

Nothing captures the imagination more than a hands-on, highly-relevant and interactive experience. This paper will describe Engineering 100 at the US Air Force Academy, a new freshman core course designed to introduce and motivate first-year students towards the engineering fields. Cadets are introduced to five engineering disciplines: aeronautical, astronautical, electrical, mechanical, and civil. By the end of the course, emphasizing just-in-time teaching and learning, the students will use each discipline to design, build, and fly a boost glider (modified model airplane) of their own creation. They use aeronautical engineering o to design the plane, astronautical engineering to launch it (using a rocket motor), electrical engineering to control it during flight, mechanical engineering to employ sturdy construction techniques, and civil engineering to build an appropriate launching pad. Emphasis is on real-world design, a systems approach to project management, and close interaction with faculty serving as coaches and mentors.

This course's organizing project gives plenty of opportunity for creativity and enough breadth to touch on all appropriate disciplines. Students are organized in small problem-solving design teams. Traditional lectures and evaluations are replaced with web-based instruction and hands-on projects. Computer tools are employed where appropriate, and students are evaluated on both individual comprehension and group execution of the project. Throughout the semester, design teams deliver two oral presentations and a final written report.

The course gives students early experience wrestling with challenging educational outcomes; students apply the systems engineering approach, frame and resolve ill-defined problems, use technology, exercise their intellectual curiosity, work with others, and communicate orally and in writing. Various assessment methods aid the instructors in determining course effectiveness, student comprehension, and student motivation toward pursuing engineering degrees.

What? Another Freshman Intro to Engineering Course?

Wait! Before tossing this paper aside, this brand-new freshman "Introduction to Engineering Systems" (Engineering 100) course really works. Here are some of the distinctive aspects of the course:

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- Just-in-time teaching/learning
- Hands-on learning
- Group designing, building and flying a class project
- Web-based self-teaching (no textbook!)
- Integrated systems engineering (not just mechanical, or aeronautical, or civil, etc)
- Lots of "motivational" on-line videos
- On-line instruction as needed
- Facilitated/taught by ALL five engineering departments (not by "subject matter experts")

Yes, this is a course developed and delivered at the United States Air Force Academy. And yes, we have developed this motivational course to help "recruit" more of our cadets to major in one of our eight ABET-accredited engineering majors. And finally, we have developed this course in response to an Air Force need for more Air Force officers with engineering degrees. In this paper we will (1) describe this revolutionary course, (2) provide the assessment data (2 semester's worth) to show what worked and what didn't, and (3) provide you with the financial and other costs in case you want to try it at your engineering college. (We also think this is an ideal course for freshmen at *Liberal Arts* colleges and universities!)

Course Design Philosophy

When faced with the challenge of creating a course that provides an introduction to five different engineering disciplines, it would be natural to divide the number of lessons in the course by five and "give" each block of lessons to the appropriate department. The result would be a fragmented course that students would see as a "shopping list" of unrelated topics. The design team for Engineering 100 specifically wanted to avoid this result. Instead we chose to create the course around an "integrating artifact," a single project providing the focus and motivation for every activity in the course. By choosing a design project requiring skills from all the engineering disciplines, we ensured the course would stay unified around solving that problem while exploring elements of each engineering discipline. We further decided this would not be just a "paper design," but that students would design, build, and test their design.

The team chose an aerospace plane – a combination rocket and glider - as the integrating artifact for Engineering 100. This was an ideal design problem for this course, because to solve the design problem students had to understand aeronautics, astronautics, structures and materials, electronics, and civil engineering issues like siting and infrastructure. In order to keep the cost of designing, building and flying such a vehicle manageable, we limited the size. The semester project involves creating and operating a sub-scale concept demonstrator and its launch/recovery facilities.

The overall goal is to provide a course to all our students to motivate and excite them about engineering. Therefore, one of our main course objectives is to have fun! Concurrently, we had to provide a framework for success, and to give them a flavor of follow-on engineering courses. We set the students up for success by stressing the importance of working as a team, using the engineering method and computer software to tackle and communicate each aspect of the project. The overall project required an integrated, systems engineering approach, and the importance of engineering to the Air Force and associated ethical responsibilities were stressed along the way.

Course Framework

The course is centered on producing the rocket-glider artifact by the end of each semester. The flying rocket-gliders are models which, under remote radio control, transition at the top of their boost trajectory into gliders that attempt to make a soft landing on a designated site. Our six-student teams design, build, and fly a fully operational rocket-glider vehicle from scratch. Powered by a 3 second, 3.4 lb max thrust model rocket motor, most boost gliders are about 2 feet long. Each boost glider has a set of control surfaces mounted with receiver-actuated servos. Flights last from 2 seconds (for an aerodynamically unstable model!) to up to 30 seconds, with the successful team able to "fly" their vehicle to a designated landing zone.

Perhaps one of the first thoughts that comes to mind is how can we teach a first year student, who may or may not be interested in an engineering major, to complete a major engineering project such as designing, building, and testing a rocket-glider. Indeed, taken at first glance the project is daunting. We solve this by breaking the course into smaller projects, typically along engineering discipline lines, so that the students can understand what they need to complete the project.

We teach topics through bite-sized morsels which will aid the students in understanding the principles they will need to design and build their boost gliders. Typically, three or four lessons of material, including in-class hands-on exercises and demonstrations, followed with some time to build and test each project where our students get a chance to apply what they have just learned. These smaller projects are the building blocks the students need to build their final project (Figure 1).

The building blocks for the rocket-glider include launch facility projects, a rocket project and glider project, and the final integrating rocket-glider project. Students are given adequate time to complete the individual projects, learning principles as they design, build, and test each product , leading to the final rocket-glider project. We describe each briefly, below:

Rocket Project

An initial project for the students is a typical rocket that many have seen before. We introduce a spreadsheet to help them design their rocket (where to put the fins, how much clay to put in the nose, etc.) so the vehicle will be stable. We also built a simple wind tunnel so each team can "fly" their rocket prior to actual launch. After the lessons on rocket motors and trajectories they build and fly a rocket.

Glider Project

Using a spreadsheet similar to the one used for the rocket, students continue their journey towards the final project by designing a glider. Concerned with the aerodynamic forces and stability such as lift, drag, and yaw, the students build gliders out of balsa wood. They attempt to hit a target from a balcony and learn some final lessons prior to bringing it all together.

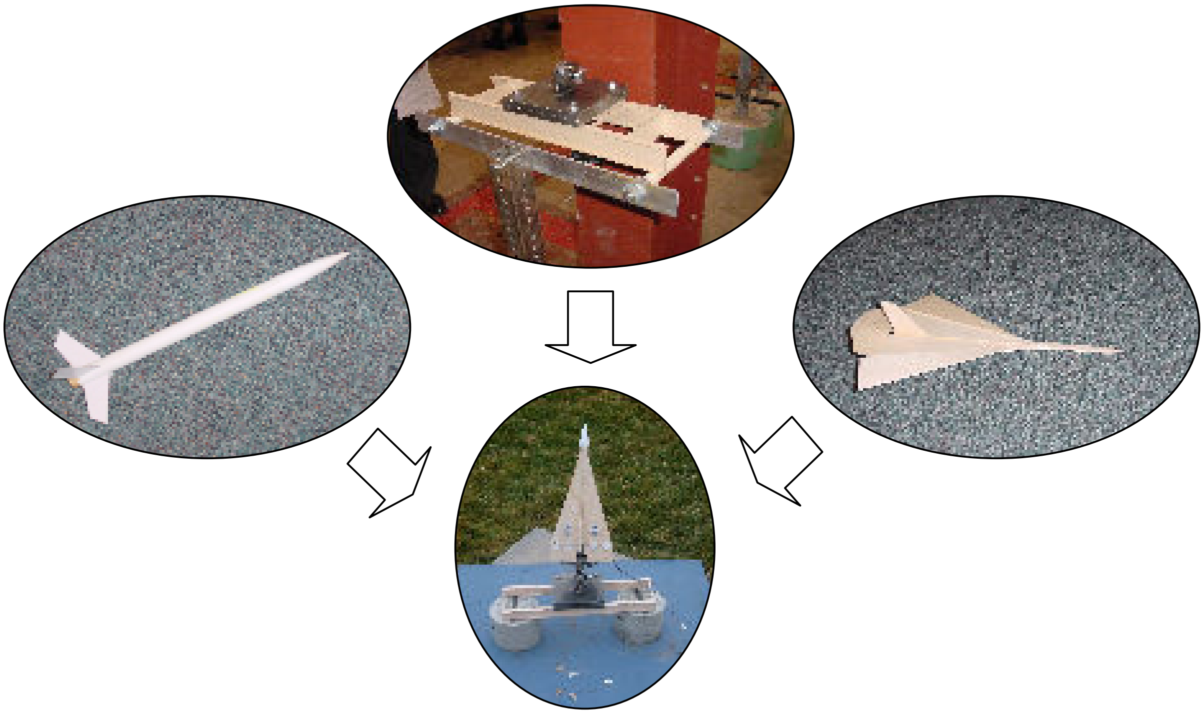

Figure 1. The "Artifact" and Supporting Projects

Launch Facility Projects
The launch facility provides the support system (infrastructure) necessary for any reasonably large system. There are two projects involved in the launch facility:

Launch Platform: The launch platform models a structure which would allow the full-scale vehicle to use the Space Shuttle launch facility. Student teams design and build a bridge-like structure from balsa wood to support a 12-pound launch pad over a scaled-down representation of the Shuttle's blast diverter/sound suppressor trench. They learn about basic structure design and loading, as well as Factor of Safety and how to incorporate it.

Launch Logic Circuit: The launch facility also incorporates a launch safety logic circuit, which students build on prototyping boards. The logic circuit accepts as inputs such variables as wind velocity, gust velocity, and range safety, and outputs a go/no-go decision. In the design and build process, the students learn about digital logic.

Final Project
Using a spreadsheet that is a combination of the rocket and glider spreadsheets, the students design the rocket-glider. The students use what they have learned during the rocket and glider projects, and a few new concepts are introduced. The new concepts are: the basic idea of radio control, sizing and selecting batteries, and working with a center of gravity that will change when the vehicle transitions to the glide phase (after the motor is ejected). Stability during both phases is discussed.

Course Mechanics
We begin by dividing the class sections into design teams consisting of five or six students. On the first day of class we give them a problem—in our course it's building a paper airplane launcher using a mouse trap and not much else—and say GO! After one class period we test, then discuss the results. What made their teams work and what didn't? We discuss the nature of engineering, following with an introduction to our five-step engineering method:

1. Define the problem
2. Collect Information
3. Create Solutions
4. Perform Analysis
5. Make Decisions and repeat the cycle as necessary

The design teams document this process in a team binder, graded at the end of each project, which is really a teaching tool to introduce them to laboratory notebooks. We use the binder, as opposed to a bound lab notebook, so that each team member can add individual exercises, in-class notes, CAD drawings, etc. throughout the semester.

For each block of instruction students are required to study (review?) the lesson materials provided at the beginning of the semester on in-house produced CD ROMs. These lesson materials include videos, readings, spreadsheets, and daily quizzes. Given this pre-class preparation, instructors can concentrate in class on assessing understanding, demonstrating concepts, and letting students apply concepts through a series of projects leading to the final boost glider flights. Not much lecture to be found during the semester; the students are actively engaged in class with hands-on demonstrations, learning how to apply the spreadsheets, and getting a physical "feel" for the concepts that support each project.

Course Requirements
So, isn't it expensive to run a course like this? Doesn't it take a lot of special equipment? And how do you convince several subject matter experts to teach this course? The answer to this last question is easy. The course is taught by a single instructor, not a group of subject matter experts taking turns teaching subjects. But how does that work, getting a single instructor to teach such a wide variety of topics in so many diverse disciplines?

Equipment
Special equipment required for this course is minimal. Equipment needed for the classroom demos is typically found in any first year Physics or Mechanics laboratory. Equipment required for building the projects is limited to small hand tools, such as wire cutters, X-acto knives, rulers, and protractors. .

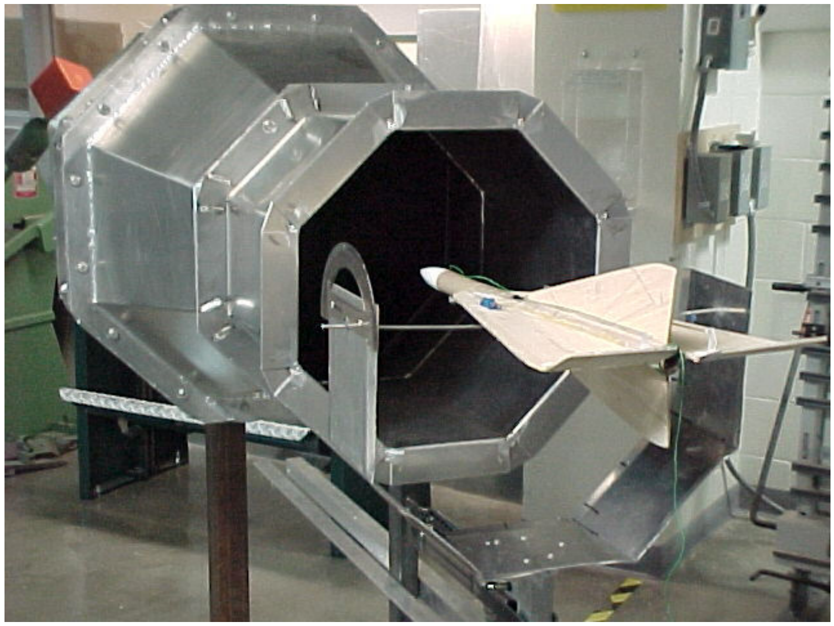

Figure 2. The Rocket-Glider Wind Tunnel

The wind tunnel is the only specialized piece of equipment used, and we build that in-house. The wind tunnel is an important part of the rocket and aerospace plane projects, since "flying" those projects in the wind tunnel tests stability and controllability before the projects are ever launched. The wind tunnel is seen in Figure 2. It cost us about $400 in materials, and took one lab technician about 2 weeks to build

The remote-control transmitters can be expensive, but even with 500 students per semester we only needed 10 of them (for 10 different channels). The number of teams trying to work at one time will determine the number of transmitters needed.

Some electronic equipment was "semi-expendable." Each rocket-glider needs a receiver, 2 servos, and a battery. We chose to use micro-servos and a micro-receiver to minimize the weight. We had special batteries made (by a local commercial battery supplier) from 4, 1/3AA NiCad cells, again to minimize weight. The battery will provide about 5-10 minutes of power for the electronics, which is plenty of time for the 30 second flight of a good rocket-glider! A switch harness is used to conserve power. Figure 3 shows the electronics required for the final project . The electronics are generally reusable from one semester to the next, but the occasional catastrophic failure of a rocket glider can cause loss of the electronics as well.

Materials
Materials required for the projects are cheap and easy to find. Rocket parts, used for both the rocket project and the final project, can be bought in bulk from Estes. Balsa wood, used for nearly all the projects, can be obtained in bulk from a number of suppliers. Other materials needed are items such as epoxy, glue, paint, sandpaper, etc. Electronic parts needed were minimal; a few wires and 3 TTL chips.

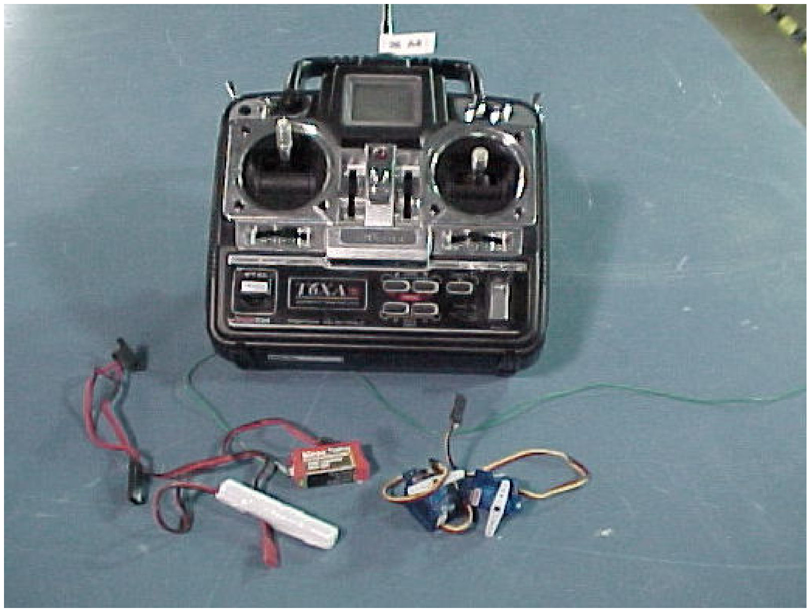

Figure 3. Required Rocket-Glider Electronics

Cost

We needed to keep costs down as much as possible, so we bought in bulk whenever we could, and made specialized equipment (such as the wind tunnel) in-house as much as possible. Our initial reusable item costs were approximately $40,000, and $15,000 for non-reusable items (balsa, glue, etc.). We've also budgeted approximately $3,000 annually for replacement of reusable items. These costs are for an average annual enrollment of 1,200 students. While most schools can charge a lab fee to offset the cost of materials and equipment replacement, we choose not to do so at the Air Force Academy. However, a modest amount per student would cover all these costs.

Expertise

We thought about having an instructor from each discipline teach the lessons relevant to that discipline. Having several different subject matter experts teach one section can cause a lack of continuity for the students, and may hamper development of the overall project and "big picture" for the students. Instead, we have instructors from each discipline teaching the course, but any given instructor teaches all of the lessons for his/her section. This means any given instructor teaches *all* disciplines. This seemed like a daunting task at first, but the level of material is fairly basic, so the faculty were able to review the engineering basics and do a credible job of teaching the lessons for all disciplines. Several unexpected benefits arose from this arrangement. We had more crossflow of ideas between departments. Teaching tips and techniques were shared between departments. More collaboration on other courses and projects occurred, since we all became more aware of one another's strengths and interests. The students also benefited, in that they saw teamwork in action. We let them know that an instructor may not have the answer to their question, especially if it fell outside the instructor's discipline. But we had a team of experts to rely on, and could find the answer by asking our team.

Course Assessment

Since we offer this comprehensive course to 600 students per semester without a preliminary test course, much of our initial assessment is to see if we are on the right track. This is accomplished by online surveys taken periodically throughout the course as the students' experiences are fresh in their minds. We ask:

- What describes the project (was it challenging or boring?)
- How much time do you spend preparing for class?
- Do you understand the computer software?
- What is your overall experience?

The data we receive allows us to modify, "on the fly", the course as it's being offered. Just in time assessment is also gained before each lesson with an on-line Daily Quiz. Each lesson's reading (about 6 -9 pages) is followed by an on-line Daily Quiz that must be completed before class. Each quiz has from two to five fairly straightforward multiple choice questions based entirely on that lesson's reading. Each quiz question is worth only 3 points (out of a course total of 1000 points!), but there are 100 quiz questions over the course of the course! So, 30% of the course grade is based on individual effort quizzes. And, the scores are automatically available to each instructor via the intranet prior to coming to class. The instructor can tailor each lesson using the feedback from their students.

Another assessment tool to gain feedback on the students' understanding of the course as we progress through the material is individual homework problems. These homework problems are assigned to individual students prior to joining their teams to tackle a project. The homework problems serve two purposes. They allow the instructor to know how well the material is being understood by an individual, and they force the student to be prepared to discuss the problem with their team during class time.

A final report and briefing at the end of the class not only provide students an opportunity to practice their oral and written communication, but also give instructors feedback on how well each team understood the basic engineering behind each project. Finally, students in all areas of study have the opportunity at the end of each semester to provide feedback on the effectiveness of the course and each instructor. These end of course critiques provide the course director and his/her team 23 data points for assessing the course as a whole. They also give insight into how well our instructors facilitate student learning.

The best way, however, to get candid feedback from students is to sit down with a cross section of the student population, give them pizza, and discuss the course. The Academy's Center for Educational Excellence conducts Focus Group discussions at the end of each semester for the course. Each Focus Group consists of thirty students. The facilitator starts the session by asking the following questions:

- What one word/phrase best describes your overall impression of the course?
- What are the course strengths and weaknesses?

Afterwards, the students discuss as a group questions that pertain directly to the course objectives. A facilitator guides the discussion of topics such as “Do you feel you attained the course goals?” A transcript of the entire group discussion is provided to the course director.

Course Success

After two semesters (academic year 2002-2003) and over 150 different boost gliders designed by nearly 1200 cadets, the answer is a resounding YES (but everyone can get better). The result has been fabulously successful at motivating students and helping them understand how the various engineering disciplines work together in a large project. This unique introductory engineering course ensures that our students:

- know the steps of the engineering method.
- apply the systems engineering approach to meet a given customer need.
- use computer software to solve problems, communicate solutions, and optimize designs.
- demonstrate the ability to work as a team.
- understand the importance of engineering to the Air Force.
- understand the importance of ethics to engineering.
- have fun!

Assessment and feedback data indicate that we have a great course that is only going to get better. Figure 4 illustrates over the first year offering (without a test course, remember!) the students give the course a thumbs-up.

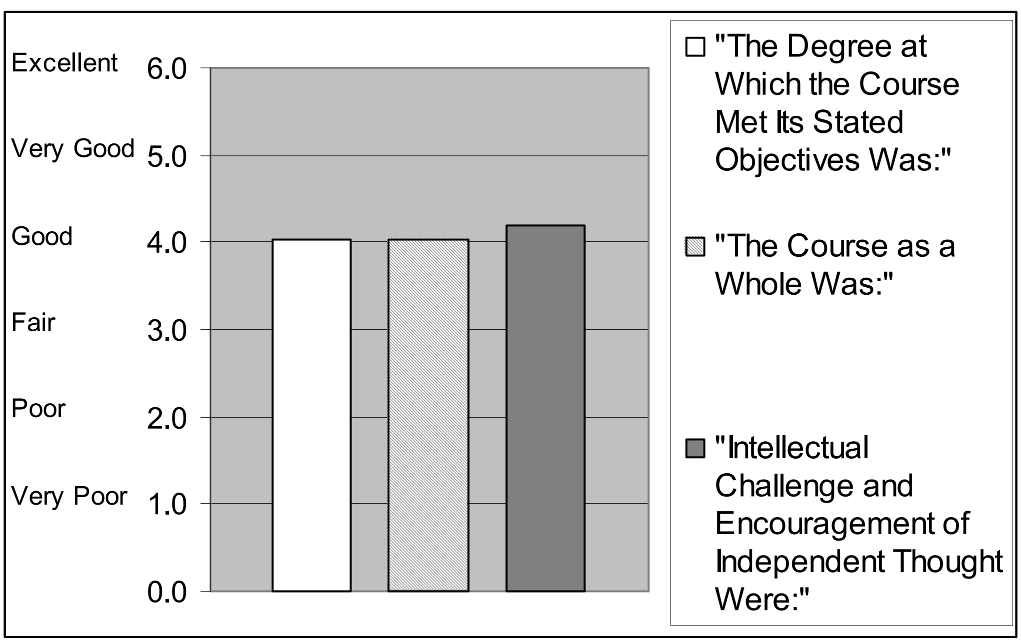

Figure 4. Example of Student Course Feedback During First Year Offering

Figure 5. "WE LOVE ENGINEERING 100!"

Future Course Direction
Since we began teaching this course, we have continued to revise and refine the contents and delivery. We continue to add hands-on demos during class, and refine the spreadsheets and other tools our students and instructors use. Our objectives have not changed since inception, nor has the basic concept of an integrated project. Initial feedback from students indicates the course is well-received. We hope this course will encourage more students to major in one of the engineering disciplines; we will be able to collect that data as our next several classes of cadets choose their majors.

A Final Word of Thanks
We should note that, beyond the authors, three other USAF Academy team members where involved in the development of this course. Capt Michael S. Warner, Astronautical Engineering, was heavily involved throughout the entire development, contributing the astronautics portion, and getting the course underway in its first year. Maj Jon S. Schoenberg, Electrical Engineering, contributed to the EE portion during development. Maj Jeth Fogg, Civil Engineering, was involved in the early stages of course concept development. As is the case in any military organization these men have moved on to different assignments.

Conclusion

A new introductory engineering course has been created at the Air Force Academy beginning in 2002. The course was organized around an integrating artifact, in this case, an aerospace plane (rocket-glider). In order to minimize cost, a sub-scale project was developed so that the cadets could actually built and fly their project. Initial assessments suggest the course has met its objectives; students learn to use a systems engineering approach to solve a problem, learn to work as a team, understand the importance of engineering to the Air Force, and, we think, are positively motivated toward engineering studies.