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Engineering Physics at a Small Liberal Arts College: Accomplishments and Challenges

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Introduction

The idea of adding engineering to the list of majors at liberal arts colleges is not entirely new. For instance, engineering at Swarthmore College dates to the 1870's [1-2]. A century later, there was a renewed recognition in the value of introducing engineering to liberal arts students [3] or of adding liberal arts to the engineering curriculum [4]. During the 1980's, the Sloan Foundation's New Liberal Arts Initiative made grants totaling $20 million in order to develop a set of courses that integrate technical and quantitative literacy into traditional liberal arts studies [5].

Many small liberal arts colleges have tried to offer an engineering option through the adoption of 3-2 programs [6]. Experience has shown, however, that very few students ultimately pursue the 3-2 route for a number of reasons—for instance, they want to continue participating in athletics or they want to graduate with their friends. Other colleges have added engineering majors. For instance, Hope College in Michigan added engineering during the 1990s using grant funding from the Fund for the Improvement of Postsecondary Education of the U.S. Department of Education [7]. Many of the existing Engineering programs at liberal arts colleges are at national, highly selective, liberal arts colleges where the acceptance rate is 50% or less, often much less. In addition to Swarthmore and Hope, highly reputed Engineering programs can be found at Harvey Mudd, Trinity (CT), Smith, Union, Bucknell, and Lafayette [8].

More recently, however, smaller, regional, liberal arts institutions have started adding Engineering to the collection of majors offered. For instance, in the 2000s, Sweet Briar College in Virginia used $1.5 million in grants from the National Science Foundation to build its engineering curriculum [9]. In Virginia alone, Roanoke College [10], Bridgewater College [11], and Marymount University [12] have all announced new Engineering majors. Many seem to be considering pursuit of ABET-accreditation but appear to be behind Randolph-Macon College.

In 2012, the faculty of Randolph-Macon College (RMC) approved a new Engineering Physics (EPHY) major. Randolph-Macon is a small, residential, undergraduate liberal-arts college in Ashland, Virginia, USA which dates to 1830 and has approximately 1500 students. The mission of Randolph-Macon is to develop the mind and character of each student. The academic program includes an extensive liberal arts core curriculum (over 40 credits) that exposes students to broad perspectives. In this paper, the authors present the back story that led to the creation of the new major, the design of the curriculum, the articulation with the liberal arts, the difficulties faced in implementation, the student outcomes and benefits to Randolph-Macon, and the goals and plans for the future.

History of Engineering Physics at Randolph-Macon College

At the encouragement of a local practicing civil engineer, Randolph-Macon first considered adding a new department of engineering during the 1980s. During that time, the President of the

College and the local engineer visited Swarthmore College [13] to learn more about their program. The conclusion at the time was that beginning an engineering program would require a financial investment far beyond the ability of RMC to support.

In 2009, Randolph-Macon adopted a new strategic plan [14]. Among the goals of that plan were: "to expand and enhance our program" (Goal II) and "to grow the College" (Goal IV). The leadership of the College recognized that in order to thrive and survive, RMC must grow. In order to do so, the academic offerings needed to expand beyond the traditional liberal arts to include new majors and co-curricular activities that were better aligned with student interests, thus making Randolph-Macon more attractive and competitive. Eleven new majors have been added in the last twelve years including nursing, criminology, and cybersecurity.

In 2010, with the continued support of a local engineer, the Physics Department Chair (Dr. Woolard), a well-established and trusted member of the faculty, determined that the time was right to introduce an engineering major in some form – one that focuses on general engineering and embraces student-athletes. In November 2012, the faculty approved a new Engineering Physics Major and in 2015, with the aid of a $300k donation, one new faculty member, a Director of Engineering Physics (Dr. McLeskey), was hired.

Engineering Physics Curriculum

The new major emphasizes the scientific foundation of engineering and was intended initially as a preparation for graduate study. Based on the existing expertise within the department and the desire for the major to serve as a pipeline to a wide variety of engineering fields for graduate study, the decision was made to focus on Engineering Mechanics with the core courses typically found in Mechanical and Civil Engineering programs (Table 1). This choice also helped make the program unique as many newer Engineering programs are focusing on Electrical and Computer Engineering. The program gives students time to explore the myriad of engineering fields over their four years of study before deciding on a specialty.

Table 1. Engineering Physics Curriculum at Randolph-Macon College. Credit hours in parentheses

Engineering Physics Courses	**Science Courses and Math Prerequisites**	**General Education Courses before 2021***
Intro to Engineering (3)	Introductory Physics (8)	Writing and Composition (4)
Statics (3)	Digital Electronics (4)	History (6)
Dynamics (4)	Physics Elective (3)	Philosophy/Religion (6)
Mechanics of Solids (3)	2-course sequence in another lab science** (8)	Arts/Literature (9)
Mechanics of Fluids (3)	Calculus I (4)	Social Science (6)
Advanced Engineering Lab (1)	Calculus II (4)	Foreign Language (12)
Capstone (3)	Multivariable Calculus (4)	Non-western course (3)***
Minimum EPHY Credits= 20	**Min. Math/Science Cr.**= 35	**Min Gen Ed Credits** = 46
Minimum Credits Required for Graduation: 110		

*Math and Science General Education Requirements are met by courses required by the major as are requirements for Computing, Experiential, and Capstone Courses.

**Students choose a two-course sequence in Biology, Chemistry, Computer Science, Environmental Studies or Geology

***The Non-Western General Education requirement is often satisfied by a course which satisfies another General Education Requirement

In addition, RMC has small classes with fewer than 25 students each. While Engineering classes are nominally organized in lecture and laboratory formats, the small class sizes allow for lots of flexibility. For instance, faculty employ peer instruction where students can work in groups of two or three on example problems while the instructor moves about the classroom or utilize think-pair-share (TPS) activities which require students to think individually about a topic or question and then share their ideas with classmates. Problems can also be tailored to the interests of the students in the room.

In addition to the core mechanics courses, students majoring in EPHY must take a sequence of Physics courses including a Physics elective (often Modern Physics). Students must also complete a two-course sequence in another lab science area (Biology, Chemistry, Computer Science, Environmental Studies, or Geology). Students majoring in Engineering Physics are required to fully satisfy Randolph-Macon's General Education Requirements. This can be as many as 66 credit hours, but because some of the requirements can be satisfied by courses in the major (for example, the lab science requirement and the Capstone requirement), the typical Engineering Physics major needs about 46 General Education credit hours. If the student has placement for foreign language, the number can be even smaller. In fall 2021, Randolph-Macon implemented a new General Education Curriculum ("Curriculum 21") with slightly fewer requirements, but slightly different categories (Pillars). For simplicity, only the Gen Ed curriculum in place before 2021 is included in Table 1.

Articulation with liberal arts

As discussed above, the Engineering Physics major at Randolph-Macon is fully integrated into the curriculum and all students must complete the same General Education sequence.

The articulation of engineering with the liberal arts was considered from two perspectives. The first is the obvious benefit of a liberal arts education to the engineering student [15]. While advances in knowledge and technology are creating excitement in science and engineering education, tomorrow's engineer must also be able to write and communicate well; consider ethics and social responsibilities; understand business; and live and work in teams as a global citizen. They must be able to think critically and problem-solve. The faculty of RMC prides itself on producing graduates with all of these so-called "soft skills" as well as the breadth of knowledge obtained by completing a large General Education curriculum.

Perhaps more interesting is how Engineering as a discipline can contribute to and be a part of the liberal arts. Modern Engineering is the application of scientific knowledge to creatively design new devices and processes that benefit society. Engineering is often thought of as one-part science, one-part art, and one-part creative design. In other words, Engineers must create while understanding the fundamental science that constrains their creations. Those engineers who merely tinker and fabricate and try to build something often fail because they do not recognize the need for both fundamental science and imagination in their designs. The grainy film clips of vintage aircraft thrashing themselves apart without ever leaving the ground come immediately to mind. Until the Wright brothers built a wind tunnel to understand the properties of wings and propellers using the scientific method while also ingeniously inventing the idea of "wing warping" to provide stability, the airplane was a great idea that was not going to work. Engineering students bring this creative mindset to their general education courses and non-majors have taken Engineering courses (particularly Introduction to Engineering Physics). The Engineering faculty have also offered Engineering-based Honors courses for non-majors.

Challenges with implementation

Helping the faculty of Randolph-Macon see Engineering as a contributor to the liberal arts helped make the new major more palatable. The plan was not, however, universally embraced.

The faculty of RMC have a strong commitment to the liberal arts tradition. The College also has a strong faculty governance model and "faculty control the curriculum." A vote of the full faculty is required in order to begin a new major. A vocal minority of faculty members believe strongly that the purpose of a liberal arts education is "to promote the common good" [16], regardless of whether or not that education leads to career. They also believe that any new curricular ideas must percolate up naturally from within the faculty rather than being driven by outside donors.

Given the faculty perspective described above, it became clear that in presenting the new major for faculty approval, it would be best to emphasize the scientific foundation of engineering and to design the new major predominately as a preparation for graduate study. For that reason, the

new major was presented as Engineering Physics rather than as simply Engineering. Engineering Physics has the great advantage of having the word "physics" right in the title. This served as a reminder that engineering has its basis in science. It also has the advantage of not being confined to one branch of engineering. This proved to be helpful in convincing the faculty that they were approving another science major, not a "technical" degree.

In reviewing the initial proposal, the Curriculum Committee felt strongly that the new major needed to include more lab courses. For this reason, a two-course lab sequence from another science field was added to the requirements. This has proven to be fortuitous in that the requirement often motivates students to pursue a minor or a second major that they might not have considered.

Although there was great support from the administration for the idea of adding some kind of Engineering to the curriculum, convincing them to commit the necessary resources to hire a new full-time faculty member took some work. Initially, the administration wanted to move forward with a Visiting Professor. The Physics Department Chair (Dr. Woolard) pushed hard to convince the administration that success was going to require the hiring of a full-time, tenure-track faculty member at the onset of the new major. Ultimately, the administration agreed.

One of the greatest challenges has been the lack of ABET-accreditation. Although the benefit of ABET accreditation was recognized from the beginning, until Dr. McLeskey was hired as the Director of Engineering Physics, no one at Randolph-Macon had experience with the ABET accreditation process. As can be seen from Table 1, the curriculum as originally constituted fell far short of the 45 credits of Engineering courses needed to satisfy ABET. Many students attending our open houses (or more specifically, their parents) ask if our Engineering Physics major is ABET-accredited. Upon learning the answer, many of these students ended up choosing another institution. This challenge has been addressed and is discussed below in the Future Plans section.

Student outcomes and benefits to Randolph-Macon

Since 2015, sixty students have graduated from Randolph-Macon with a major in Engineering Physics (Figure 1). One-fourth have gone directly to graduate school while the remainder have gone directly to work in technical fields (Table 2). For the most part, graduate programs have not required remedial work although students interested in Civil Engineering have typically been asked to take one or two undergraduate courses in their area of interest (geotechnical, hydrology, etc.) before starting their graduate studies.

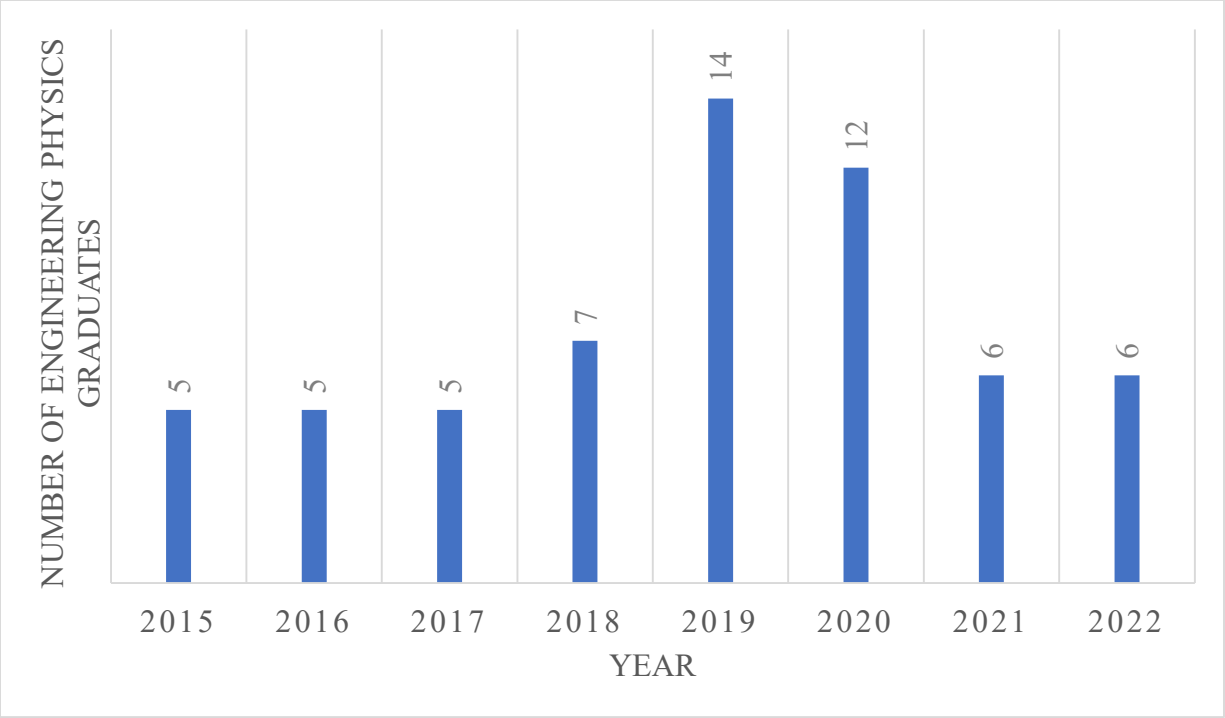

Figure 1. Number of Engineering Physics Graduates from Randolph-Macon College by year.

The Engineering Physics major has been particularly attractive to student-athletes and fully fifty percent of the EPHY graduates participate in intercollegiate athletics. Approximately one third of all RMC students play a sport (at the Division III level) and the College has gone out of its way to make it possible to be a successful Engineering student as well as an athlete, making this program highly attractive to students in that category. This is done by keeping classes between about 8:00 am and 4:00 pm (practices are after 4:00 pm and before 8:00 am) and being flexible on the occasions when a student must miss class for an athletic event.

In addition, one third of the EPHY graduates have been women. No special recruiting actions have been undertaken to attract women but the same things that attract all students (small class sizes, a liberal arts education, the opportunity to play a sport) have been attractive to female students.

Of the sixty EPHY graduates, ten have double-majored (in Chemistry, Computer Science, Economics, Environmental Studies, Mathematics, or Political Science). Many have chosen to add one or more minors (Physics, Math, Computer Science, Biology, Communication Studies, Asian Studies, Spanish, etc.). For many students, the requirement for including a Physics elective and the two-course sequence in another science have proven to be highly valuable. For instance, the Naval Surface Warfare Center at Dahlgren, Virginia has hired a dozen EPHY alumni in large part because of the breadth of their education. The two-course sequence has often led to a minor (Computer Science and Biology) and these skills have helped the students gain admission to top graduate programs.

Table 2. Graduate Schools attended (full-time upon graduation) and Employers of Engineering Physics majors from Randolph-Macon College. Number of students is in parentheses.

Initial Employers of Randolph-Macon EPHY graduates (45 students)	**Graduate Schools (15 students)**
Northrup-Grumman (Florida)	Virginia Tech – Civil (2)
Naval Surface Warfare Center – Dahlgren, VA (12)	Virginia Tech – Engineering Mechanics (2)
Duke Power	University of Virginia – Mechanical and Aerospace (2)
Dominion Energy	University of Virginia – Materials Science
Lutron Electronics (electronic window shades)	Virginia Commonwealth University – Mechanical
Federal Reserve Bank of Richmond (Currency Technology Office)	Coastal Carolina – Coastal
TemperPack (insulated packaging)	Colorado State – Civil
Schnabel Engineering (Geotechnical)	Georgia Tech – Mechanical
Waco Inc (Industrial Remediation)	Duke – Biomedical
Townes Site Engineering	Old Dominion University – Robotics
Stantec Civil Engineering	Rutgers – Law
Deloitte Consulting	University of Vermont – Sustainable Enterprises
G.D Spa (high speed manufacturing equipment)	
Team Fishel (utility construction)	
ChemTreat (Industrial Water Treatment)	
Genworth Financial	
Pillar Construction (Civil Engineering)	
HMI (Civil Engineering)	
Martin Marietta Materials	
Norfolk Southern Railroad	

Future plans

From the beginning of the Engineering Physics program at Randolph-Macon, there has been a desire and an intention to seek ABET-accreditation. The Director of Engineering Physics (Dr. McLeskey) was hired, in part, because of his experience with ABET.

Building upon the success of the EPHY major (Figure 1) as well as a greater appreciation for the role that Engineering can play in a liberal arts curriculum, the faculty approved a new major in Engineering (ENGR) in March 2019. This new ENGR major is designed to earn ABET-accreditation in 2023 and was formally announced in December 2019 [17]. As is clear from Table 1, in order to make ABET-accreditation a reality, the number of required Engineering courses needed to be increased (ABET requires Engineering = 45 credits, Basic Science and Math = 30 credits). The new major includes the same core of engineering mechanics plus hands-

on project-based design and analysis courses as well as several electives (Table 3). Six Engineering majors are scheduled to graduate in 2023, eleven in 2024, and thirteen in 2025.

Table 3. Engineering Curriculum at Randolph-Macon College. Credit hours in parentheses

Engineering Courses	**Math and Science Courses**	**General Education Courses***
Intro to Engineering (3)	Introductory Physics (8)	Writing and Composition (4)
Statics (3)	Digital Electronics (1)	History (6)
Dynamics (4)	Mathematical Physics (3)	Philosophy/Religion (6)
Mechanics of Solids (3)	Calculus I (4)	Arts/Literature (9)
Mechanics of Fluids (3)	Calculus II (4)	Social Science (6)
Computer Aided Engineering Design (4)	Multivariable Calculus (4)	Foreign Language (12)
Thermodynamics (4)	Differential Equations (3)	Non-western course (3)**
Solid Mechanics Lab (1)	Math/Science Elective	
Fluid Mechanics Lab (1)		
Computer Aided Engineering Analysis (4)		
Engineering Capstone I & II (6)		
Digital Electronics (3)		
Two additional elective Engineering courses (6)		
Minimum Engineering Credits = 45	**Minimum Math/Science Credits** = 30	**Minimum Gen Ed Credits** = 46
Minimum Total Credits for Graduation: 110***		

*Math and Science General Education Requirements are met by courses required by the major as are requirements for Computing, Experiential, and Capstone Courses.

**The Non-Western requirement is often satisfied by a course which satisfies another General Education Requirement

***Students choosing the Engineering major who do not have placement into upper level foreign language, may need to complete more than 110 credit hours in order to graduate.

Even with the addition of the new ENGR major, the existing EPHY major remains in place. The EPHY major offers students more flexibility. For instance, it is possible to begin the EPHY major as a sophomore and still graduate in 4 years because the curriculum is not as "serial." It is also far easier to double major or select multiple minors with the existing EPHY major. Finally, as mentioned above, approximately one-third of RMC's students are athletes. While the new ENGR major can accommodate these students and most students are selecting the ENGR major over the EPHY major, the flexibility of the existing Engineering Physics major offers more choices.

Some questions remain unanswered: Will colleagues in the humanities continue to support Engineering as the program grows and resources are reallocated? Will Engineering Physics

continue to thrive as the new Engineering major becomes fully implemented? How can the curriculum be updated to continue providing the necessary rigor while attracting students who want "hands-on" education?

Nonetheless, the trends are positive. Since 2020, RMC has hired another engineering faculty member; reconfigured space and purchased new equipment to support the new ENGR courses and labs; designed literature to better communicate with the public about our engineering studies; and spread the word with regional employers about our emerging ABET program. The engineering discipline has been successfully integrated into the curriculum at Randolph-Macon College and is thriving!

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