The Impact of Fluid Dynamics Research on Undergraduate Education

Aric Martin Gillispie, University of Central Oklahoma

Aric Gillispie has been actively involved in fluid dynamics research since 2012, writing and receiving several grants for his research and co-authoring numerous papers. Aric received his B.S. in Mechanical Engineering from the University of Central Oklahoma in May 2016, and will be completing his M.S. in Mechanical Engineering by May 2017. After completion of his M.S. he plans to pursue a career in academia either through continued education in a PhD program or by entering the workforce.

Mr. Adam Dorety, University of Central Oklahoma

Adam Dorety is currently a senior at the University of Central Oklahoma (UCO). He is involved in Fluid dynamics research observing entropy loss through tee junctions for low viscosity and reynolds numbers fluids. He is also a past UCO chapter of the American Society of Mechanical Engineers chair, vice-chair and treasurer. He began his research on the Underwater Remote Operated Vehicle (ROV) as well as an Unmanned Aerial Vehicle (UAV). He hopes to graduate in 2016 and join the workforce. His experience with undergraduate research has undoubtedly strengthened his commitment to mechanical engineering.

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Professor Lemley teaches thermo-fluid engineering and works with undergraduates to perform fluid dynamics research that is mostly focused on small scale flow problems. He is currently an Assistant Dean of Mathematics and Science and a Professor of Engineering and Physics at the University of Central Oklahoma, his home institution for more than fifteen years. Previously, Professor Lemley worked as a mechanical engineer in the power industry. His bachelor's degree is in physics from Hendrix College and his M.S.M.E. and Ph.D. were earned at the University of Arkansas.

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Abstract

The obtaining of an undergraduate degree concludes a successful student university career. For many pursuing an undergraduate degree in Mechanical Engineering, the process can be tedious and difficult. Much like an engineering design, an engineering education requires specific tools to see the problem from design to production. For many, the desired solution to producing the degree is supplemented only by an introductory design class, a few hands on laboratories that provide an introduction to a few key basic concepts, and a capstone course that requires the implementation of the acquired knowledge in a final design project intending to mimic the design process that would be expected in industry. However, undergraduate research can go beyond complementing the university education. Participating in undergraduate research can supplement an engineering education to provide the tools necessary to be successful as an engineer in industry or lead into a fruitful graduate education.

Specifically, undergraduate research in fluid dynamics can allow for the engineering process to be viewed, performed and reevaluated on a continuing basis as the increasing level of coursework allows for a greater amount of knowledge from which to innovate. An ideal case for engineering education to benefit from fluid dynamics research would begin with the participation in a “bridge” program that allows for incoming students to experience the research and design process behind current fluid dynamics problems that can be developed upon throughout an educational career. The “bridge” program would lead into continuing academic research and experimentation in a fluid dynamics area of interest. As the student’s knowledge base expands, the overall engineering process becomes well rounded and refined through practical experience in furthered engineering research. The techniques and ideas that develop through research can be employed in educational coursework within or outside the field of fluid dynamics.

To evaluate the benefits of research on an undergraduate education in mechanical engineering, the implementation of fluid dynamics research is explored for the case of a student who is involved in academic research from the beginning of the university career through the completion of a master’s thesis in an accelerated bachelor’s, master’s program. Specifically, the use of engineering software for design and simulations and the technical skills for fabrication and experimentation, and the practical benefits these have on education when hands-on approaches are taken in the classroom will be explored. The educational aspects of fluids dynamics research can go beyond exploring minimally studied subject areas. The specific skills and techniques required to solve engineering problems that are being learned will consistently provide an educational edge in the classroom where innovative solutions to problems are expected. Additionally, two more cases will be explored; one in which a student has limited involvement in research, and a third case: a student is introduced to research in the senior year of his undergraduate degree.

Ultimately, the research and educational experiences can come together in producing an innovative and industry-level capstone design project that could lay the foundation for a successful graduate thesis or dissertation if desired. Undergraduate research throughout an

engineering education can provide a fuller look at engineering technologies that allows for innovation and well-rounded thinking that can produce the solutions to academic, scientific, and practical problems alike.

Introduction

With ever-developing technological advances, it is becoming increasingly important to obtain some form of post-secondary education. It is projected that within the next five years that greater than 60 percent of all jobs within the United States will require post-secondary education[1]. Additionally, within that same time frame greater than 90 percent of traditional STEM jobs will require a college education[1]. For this reason, it is becoming necessary to retain STEM majors and graduate successful workers. Of particular interest in this case are students within Engineering, though the premise can be applied to any major within the STEM field.

A successful engineer should be able to think through the system dynamics and interactions, make estimates, and conduct experiments; each of which fall within the greater skill of engineering design[2]. A traditional engineering education will incorporate lectures, a few proofs, a small number of hands on laboratories that relate to some of the topics being discussed, and are concluded with a capstone course that should serve as the culmination of all other coursework and demonstrate the ability to follow the engineering design process. However, due to the low number of retention (around 62 percent for all STEM majors[1]), and less than 5 percent of the nationally awarded degrees in engineering[2], it is possible that the minimum engineering curriculum may not be enough to successfully graduate engineers.

If the goal is to produce engineers that can effectively contribute to the work force, then it would be necessary that the student understand direct engineering applications[3]. Curricula for in-class lectures should highlight real world applications, and laboratories should serve to further enhance the understanding through physical models. Furthermore, engineering laboratories should teach the necessary skills that an engineer should possess such as: the ability to properly use instrumentation, create models, conduct an experiment, analyze data, and ultimately design[4]. Additionally, a student should develop a deeper understanding of safety, communication, teamwork, and ethics[5]. Assuming that each of these objectives is being met, students interested in engineering should have the confidence and the ability to complete an engineering education. If this is currently not the case, then clearly some form of supplement to the education is required. Undergraduate research is often seen as an extracurricular compliment to an undergraduate education. However, undergraduate research can serve as more than a complement; undergraduate research can serve to provide the necessary supplement to produce successful and confident engineers that are ready for the workforce or post-baccalaureate education.

To evaluate the benefits of research on undergraduate education the case of co-author Gillispie who is involved in academic research from the beginning of the university career through the completion of a master's thesis in an accelerated bachelor's, master's program is discussed. Additionally, co-authors Dorety and Meier's achievements are explored, having limited fluid dynamics research exposure and fluid dynamics research only during the senior year of college respectively. Specifically, the impact of Fluid Dynamics research on undergraduate education is being observed beginning with a summer bridge type program preceding the freshman year of college, that leads into a freshman research position. The subsequent years of undergraduate education should then see continued research that is supported through the writing of university-wide grants such as the University of Central Oklahoma's Research, Creative, and Scholarly Activities (RCSA) student grants. Finally, the research should seamlessly transition into directly influencing the capstone design course, and if desired lead into the writing of a graduate thesis. *Table1* maps the achievements of each student graphically through each stage. Though the specific example of fluid dynamics research is being explored, this approach has direct application in all STEM majors.

Summer Bridge Program

A summer bridge is designed to give incoming undergraduate students the background, frameworks, tools, and skills necessary to promote retention within the STEM majors[5]. Many programs serve primarily to teach group participation and communication through a collaborative design project. Furthermore, other aspects of the program often emphasize university resources, and provide an introduction to the tools necessary to succeed. The project that co-author Gillispie worked on was within the field of fluid dynamics. Co-author Dorety also attended the summer bridge program but worked in underwater robotics. Co-author Meier did not attend Summer Bridge.

Fluid Dynamics is not typically taught in any form of secondary education, so the STEP@UCO Summer Bridge program (NSF award 0336392) served to provide a very broad introduction to this new subject area for co-author Gillispie. The program was comprised of several parts. First, an underlying design project was worked on throughout the duration of the program. Despite being aimed at Fluid Dynamics, the project served to incorporate mechanical and electrical engineering components. The specific project would serve as the prototype for a portion of the current senior level capstone project. For that reason, working consistently on this project taught the group to learn to work to solve the design problem, and also to collaborate with other more educated students in the field. Second, an introductory literature review was conducted on current fluid dynamics problems. With no background, many of the researched papers seemed to be very academically advanced to the involved students. However, it provided an opportunity to begin developing research skills such as utilizing the libraries and databases to discover relevant materials. Finally, the program concluded with a design presentation. The presentation served as a showcase of the physical project that was developed as well as the chance to explain higher level material to students within other groups. With each student having roughly the same prior education, these discussions allowed for a deeper understanding of the introductory concepts being discussed at common level.

Co-author Dorety went through a similar experience, but with an emphasis on underwater robotics. The summer was an introduction to: the engineering design process, basic components, basic circuit design and underwater robotics. In the summer bridge program, he went through a portion of the required textbook for the university's introductory engineering design course with the faculty advisor. The project required the learning of basic circuit theory and soldering, so as to develop a prototype underwater remotely operated vehicle. The focus of the research was on how to increase the speed and proficiency of navigation through a course with tasks to pick up and move objects underwater while not entering certain areas or touching specific objects. The summer allowed for a glimpse into engineering work, specifically utilizing the engineering design process to create a unique design solution. Though the summer bridge project was not in the field of fluid dynamics, the research on underwater robotics provided a thorough introduction on engineering techniques, as it focused on electronic components and circuitry.

Co-author Meier did not have any involvement in a summer bridge type program. Furthermore, he would not gain any research experience until the senior year.

After the conclusion of the program students were encouraged to remain involved with research and were compensated for the first two semesters so long as they remained in a STEM major. This promoted retention and research involvement for that first critical year, where many students are likely to change majors. It is more difficult to abandon an area for which interest is already being developed and a knowledge base is being developed.

Freshman Level Research

The first year after the summer bridge program is critical for two reasons. First, many students will typically change majors, and statistically will even seek majors outside of STEM. Summer bridge participation and first year compensation promotes STEM major retention. Second, it further establishes the research skills that were taught within the program. This first year is critical in establishing the engineering mindset that will promote success within the program for the remaining college career.

Immediately following the summer bridge program, there should be a freshman research project to encourage engineering skill development. In co-author Gillispie's particular case, the summer design project was implemented in practical fluid dynamics research. The apparatus that was created was integral in the senior students' research, and seeing that work used for a practical purpose was invaluable. Furthermore, with an introductory background in fluid dynamics at this point, more fruitful conversations can take place about the field. While attempting to learn and better understand the complex engineering principals within the summer bridge program could be daunting, assisting in apparatus fabrication and design, and helping to carry out experiments serves to develop those skills that will be implemented independently in the coming semesters.

Typically, at this point, there will be no coursework dealing with fluid mechanics, fluid dynamics, or even the related heat transfer and thermal fluids courses. However, the research within fluid dynamics begins to take a fuller shape as courses within Calculus and physics are completed. Furthermore, the entry level courses often teach computer programming and present an introduction to common computer aided drafting (CAD) software as well as simulation software. Without the ability to fully understand the physics behind the freshman research project, simply learning to make models, carry out simple guided simulations, and writing simple programs to aid in computations, further grows the skill set that was being developed through the summer bridge program.

Most engineering programs have an introductory engineering design course. With the background from Summer Bridge, choosing an introductory design project was made simpler for with the developing skill set to include proper research techniques. Furthermore, the experience in giving a technical presentation would further aid in the design presentations. Even at this level, it was clear that students who were actively involved in research had far better performances within the class.

Ultimately, with a freshman design project underway or complete, the students should be prepared to write the first grant to fund future research. Even with minimal understanding, thorough research should allow for the student to develop a simple and unique engineering design to address an area that would make a contribution to the field. In co-author Gillispie's case, an RCSA grant was prepared by the student through thorough research on minimally studied areas within fluid dynamics. Ultimately a topic was selected that there was minimal research on. For this reason, the student would be required to create a model to solve the problem being addressed (Figure 1.), run a simple simulation on that model, design the model, conduct experiments, and analyze the results. After only a year of introductory research, a student would be fully prepared to, in a basic form, take on the entire engineering design process. Co-author Dorety continued to work on the summer bridge project, specifically working on improvements and learning tools and techniques to further develop the design.

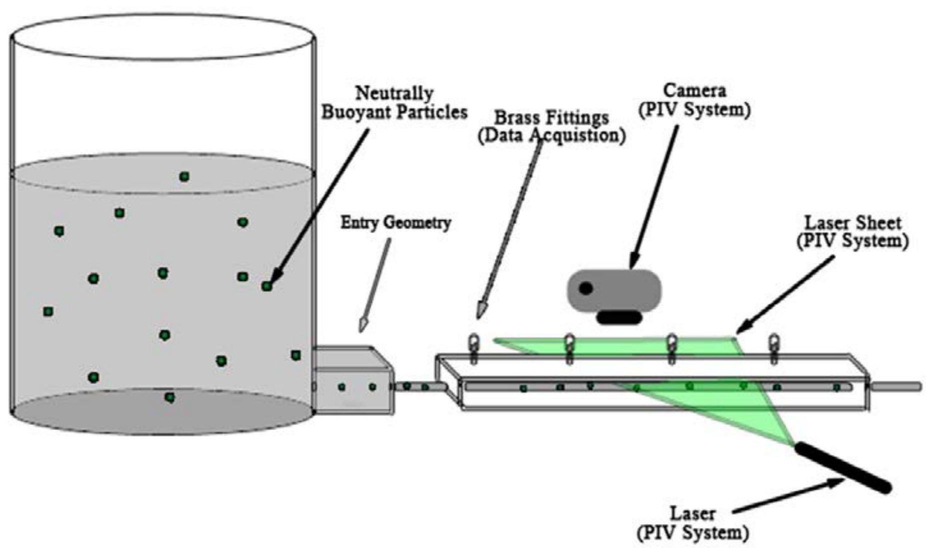

Figure 1
The concept for the RCSA grant was developed. The experimental setup was designed to determine the entropy generation for developing flow in a rectangular channel using a method of particle image velocimetry developed at the University of Central Oklahoma.

Grant Funded Research

After the freshman research project was completed, the now funded grant project for co-author Gillispie would provide an opportunity and financial incentive to conduct research for another year. For the second, third and consequent years prior to the senior year, research should be sustained as relevant coursework is taken to develop a fuller understanding of the research project and coursework simultaneously. In this instance, grants that were targeted at investigating under researched fluid dynamics areas were written and fulfilled. Ultimately, the project would require a deeper knowledge of fluid mechanics, so a self-study ensued. Within the same year, relevant fluid mechanics courses were completed. The result was a deeper relevance of the researched area, and, of equal importance, a more lucrative classroom experience that was evidenced by a deeper understanding of the course materials. Co-author Dorety worked briefly after freshman year on an aerial R.O.V. learning how to create simulations in industry leading simulation software and design three-dimensional models and assemblies in relevant CAD software.

Within the research, more advanced calculations could now be conducted, and independent thinking and design was able to be carried out. In order for co-author Gillispie to satisfy the grants, an experimental apparatus had to be designed to satisfy the fluid dynamics research. The CAD model (Figure 2) was created using some of the introductory skills gained in the first year of coursework, and these skills were further honed as independent learning had to take place. Ultimately, modeling skills that would be closer to industry level were being formed. Furthermore, basic simulations and programs were conducted and written to aid in preliminary design and calculations. After creating appropriate models, fabrication of the apparatus took place. In many institutions, students will not be required to learn simple machine shop skills and apply design and manufacturing techniques often learned in mechanical engineering design courses. Fluid dynamics research was ultimately the only avenue for these skills to be developed for co-author Gillispie. Co-author Dorety also learned these techniques and skills through his research with underwater robotics.

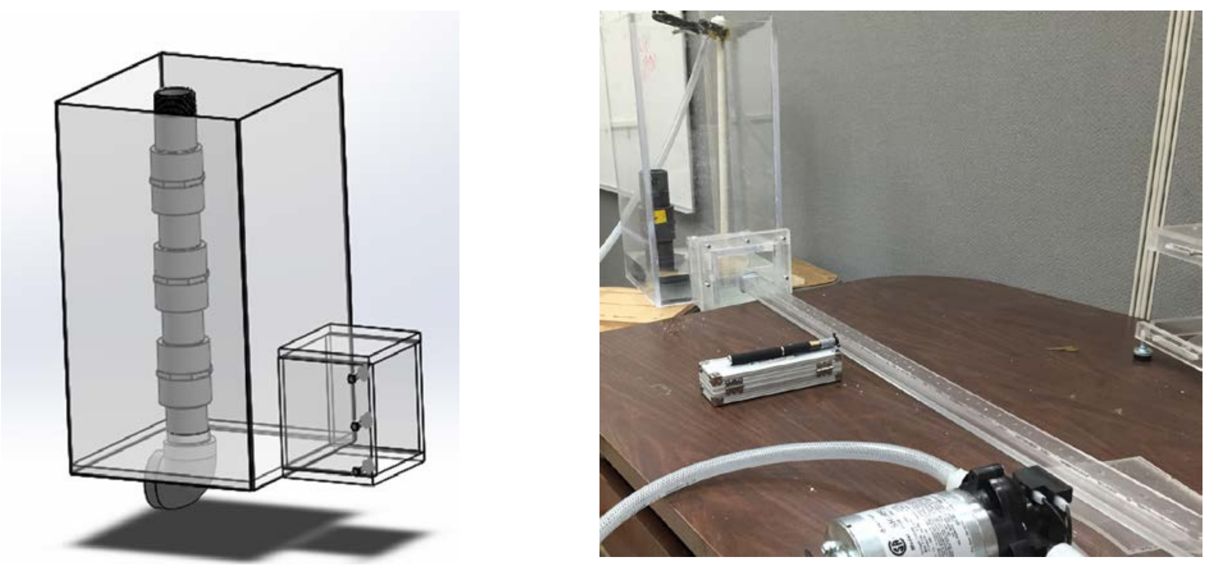

Figure 2
The concept for the experimental setup was translated into a CAD model to determine the best design. Ultimately, the model was translated into physical setup where experiments could be conducted.

Conducting fluid dynamics research throughout the years between the freshman research project and the capstone course provides rewarding opportunities to further explore topics that will not necessarily be discussed in undergraduate courses. Additionally, these years are invaluable to develop and hone the skills necessary to successfully complete a senior level engineering design project. Ultimately, as the intermediate years of research are concluded, the student should have gained some industry level knowledge on the relevant engineering techniques. The framework should be in place to produce an innovative and industry level capstone design project that could lay the framework for a graduate thesis or dissertation.

Capstone Course and Design Project

Most engineering programs are concluded with a capstone course designed to see a student team exercise all of the knowledge gained in prior coursework to follow the engineering design process to discover and solve a problem at an industry level. Without prior research experience, a student only has past knowledge from which to generate problems and solutions which was learned in a classroom environment where there is minimal room for creativity and trial and error learning, as most of the work is centered on analytical problem solving rather than design. However, with practical research experience the skill set is far broader as there has already been experience with investigating problems and designing solutions. This skillset will create a distinct advantage for the senior capstone design course and into industry.

For a student actively involved in Fluid Dynamics research for each year leading to this course, clearly it would be most advantageous to parallel a capstone design project with ongoing research. For this reason, a student may draw not only from relevant course work but also techniques, problems, and solutions that have arisen from past engineering design processes. Therefore, the level of the capstone project should be at a much more competitive level than those students that take the traditional approach to the undergraduate engineering education.

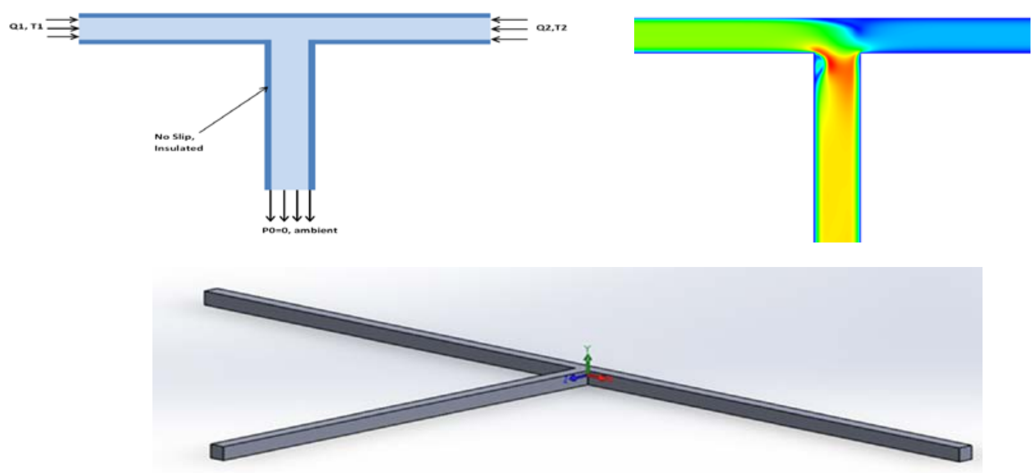

Figure 3
The senior level capstone design course used the same processes and techniques learned in the intermediate years of undergraduate research to independently develop a problem, create a CAD model, and ultimately conduct simulations that were at a much higher level.

In this case, the chosen project was a deeper and more advanced continuation of the prior three years of fluid dynamics research. From the start, an advanced engineering design approach was developed and utilized that caused computational research to drive the ongoing design. In short, computer models and simulations were implemented at each stage to insure proper design to satisfy the established requirements. This approach was of course influenced by the various skills that were developed outside of the classroom within the research laboratory. The design began with extensive CAD modeling that was immediately used to conduct simulations (Figure 3). At this point relevant coursework has been completed or is in progress, so the simulations can be independently designed to accurately apply realistic boundary and operating conditions which is important in conducting simulations. After conducting preliminary simulations and during the process of carrying out more focused simulations, the physical experiment can be constructed to mirror the modeled setup and boundary conditions. This greatly cuts down on the time required to troubleshoot an experimental apparatus and allows for a more efficient use of time.

Since the design project is a continuation of all the past years of research, the saved time allows for things such as automation and novel techniques to aid in the conducting of the current research. Additionally, side research areas and problems can be developed that, at this point, should be entirely original and worthy of a graduate thesis. To this end, the senior level project should far exceed expectations and be at a leading level. Additionally, as there has been extensive practice on technical writings through the writing of grants and publishable results, the technical reports that should complement the engineering design project will be well developed and demonstrate an understanding for the material that exceeds expectations.

Co-authors Gillispie, Dorety, and Meier all gained experience outside of the traditional college experience by being involved in fluid dynamics research. This experience will prove invaluable beyond graduation whether in industry or in graduate studies.

Graduate Thesis

For those who wish to continue education beyond the baccalaureate degree, a graduate thesis would be the logical next step. Co-author Gillispie has taken the route of an accelerated bachelor's, master's program. For programs that offer an accelerated Master's degree option, the thesis could come as early as the following semester. In many cases, a student would not be prepared to develop a thesis; however, with no less than four years of past research experience on the fluid dynamics field, a thesis in the same field is simply the next logical step. Each year of research that is built upon the previous (with each year pursuing a novel and under researched area) should lead to an entirely unique graduate thesis that undoubtedly advances the field. Additionally, the graduate coursework can be aimed directly at the field of interest, in this case fluid dynamics. Finally, all the past years of reading research papers and conducting self-studies of the material will yield the most beneficial graduate career that allows active participation in the lectures, where intelligible conversations about past discoveries and future advances can be held.

Long term Cases

A recent study has been conducted to determine the impact of fluid dynamics research on undergraduate education at the University of Central Oklahoma[9]. The study specifically looks at the current status of recent graduates from the engineering program. This study is not conclusive, but has been and will continue to be expanded in the coming year (Figure 4). Currently, it shows that 100% of students involved have graduated or are on their way to graduating with a degree in engineering. Due to the nature of the research, it is expected that a majority of those involved enter into a mechanical engineering field. Also, the research is often centered on data acquisition and automation, which has obvious appeals and benefits to electrical engineering majors. Additionally, 20% go on to pursue higher education or a terminal degree. 88% are currently employed or continuing education. Furthermore, the study[9] shows that 78% of the students have co-authored one or more papers in a conference paper or national academic journal, which is very uncommon for most engineering programs. *Figure 4* shows the breakdown to date of the selected paths of students involved with fluid dynamics research at the University of Central Oklahoma after completion of their undergraduate studies.

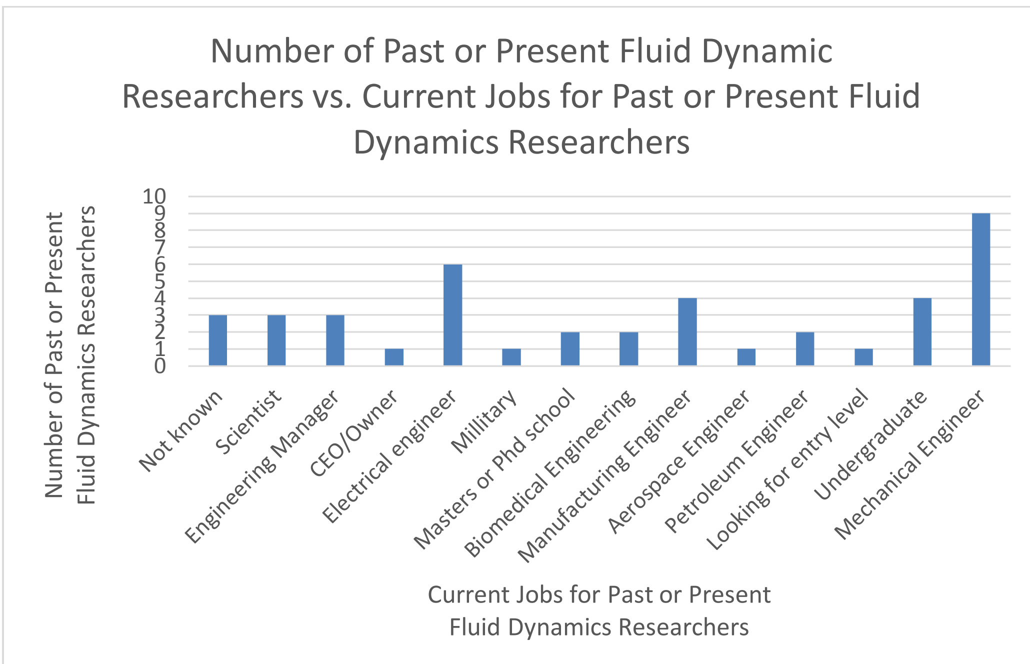

Figure 4: Current Jobs of Fluid Dynamics Researchers

Conclusion

With the ever expanding STEM field (particularly engineering), and the growing demand for graduates with a college degree, it is becoming increasingly important to retain incoming engineering majors. This retention starts with a summer bridge program that spawns interest in a specific subject area through participation in some sort of tangible design project. Students must then be encouraged and incentivized to continue research. If engineering students can be retained through the critical first year, then they are far more likely to continue within the major and the research. Immediately following the first year students should be encouraged to attempt to fund subsequent years of research through internal or external research grants. This will allow for a college career that develops the skills that the workforce requires for success. The intermediate years will ultimately be concluded with a capstone design course that seeks to implement all of the skills that have been developed through integrated research. After the completion of one or more years of unique research, students will be more than qualified to develop an original graduate thesis that seeks to advance knowledge in the field. Ultimately, undergraduate research throughout an engineering education can provide a fuller look at engineering technologies that allows for innovation and well-rounded thinking that can produce the solutions to academic, scientific, and practical problems that face companies, industries, and the world.

	Freshman Year	**Sophomore Year**	**Junior Year**	**Senior Year**	**5th Year (Graduate)**
Relevant Coursework	Calculus Physics Programming	Statics Dynamics Thermodynamics	Fluid Mechanics Thermal Systems	Capstone Fluid Dynamics Heat Transfer	
Accomplishments*					
Gillispie	Oklahoma Research Day Freshman Research Grant	Oklahoma Research Day RCSA Grant Co-author a conference paper.[11]	Oklahoma Research Day RCSA Grant Regional Conference Presentation Co-author a conference paper[9,10]	Oklahoma Research Day RCSA Grant ASEE Conference Paper Presentation	Oklahoma Research Day RCSA Grant Co-author a paper for International Mechanical Engineering Congress and Exposition 2016 Thesis Defense
Dorety	Regional Conference Presentation			Oklahoma Research Day RCSA Grant ASEE Conference Presentation	
Meier				Oklahoma Research Day National ASEE Conference Presentation	

Table 1: Accomplishment Summary for Co-Authors Gillispie, Dorety, and Meier.
The accomplishments of each of the three students are mapped from the beginning of their university career through completion of their undergraduate degree and beyond.

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