



UNIVERSITY *of*
DENVER

DANIEL FELIX RITCHIE SCHOOL
OF ENGINEERING & COMPUTER SCIENCE

STRATEGIC PLAN 2022

DRAFT AS OF DECEMBER 29, 2016

Forward. ***Faster.***

Table of Contents

Executive Summary	1
Strategic Plan 2022.....	5
Investing in Excellence.....	11
Strategic Objectives.....	13
Appendix.....	26
Appendix A. Strategic Planning Committee	27
Appendix B. 2017 Amplify Advisory Committee	28
Appendix C. 5-Year Financial Plan	29
Appendix D. Undergraduate Student Survey Findings	36
Appendix E. Faculty Size and Composition under Strategic Growth.....	39
Appendix F. Ratings and Rankings Strategy	41
Appendix G. Inclusive Excellence Strategic Plan	45
Appendix H. Undergraduate Excellence Strategic Plan	59
Appendix I. Professional Master's Degree Program Strategic Plan.....	74
Appendix J. Research Strategic Plan.....	90

Executive Summary

The Daniel Felix Ritchie School of Engineering & Computer Science (RSECS) proposes an aggressive strategic modernization plan for the next five years, consistent with and amplifying the University of Denver's IMPACT 2025 Strategic Plan and reflecting increased demand at all levels for science, technology, engineering and math (STEM) expertise. Over the next five years the Ritchie School will meet its mission of *advancing technical and scientific knowledge and capabilities to improve quality of life for our global society* by focusing its research and teaching on two Global Goals: **Develop and Inspire Healthy Global Citizens** and **Create a Smart, Sustainable World**.

The School is at the forefront of inquiry and discovery to address significant societal goals locally, nationally and internationally. Faculty are dedicated to collaborative, inclusive discovery and knowledge creation. They work across disciplines within the school, around the DU campus, and partner with industry, government, and universities across the globe. These Global Goal will focus incremental investment in research capability across five areas: Artificial Intelligence, Biomechanics, Cyberphysical Security, Robotics, and Smart Cities.

Building excellence across the undergraduate experience, and in inclusive excellence, are operational necessities for the Ritchie School. The best U.S. undergraduate institutions have moved aggressively towards experiential, challenge-based, project-oriented, diverse-team, and community-connected approach as exemplified by the [National Academy of Engineering's Grand Challenges](#) and the [UN's Sustainable Development Goals](#).

The Ritchie School will modernize its educational program for undergraduate students. The current pockets of excellence within the program will be strengthened and expanded to meet the needs of 21st century learners. The School will place strong emphasis on learning inside *and* outside the classroom so students can learn hands-on as they align their passion with their purpose. This is critical to the School's diversity and inclusive excellence objectives.

By Fall 2021 the undergraduate student body will be at least 50% female and at least 50% of students will be of color, more than doubling the current representation. The percentage of first generation students will also increase to at least 20% of all students, up from 16% currently.

Professional Master's programs focused on specific job skills that help students gain a new job or advance in an existing position will grow at far faster levels than degrees at any other level. Among these, the fastest growth and greatest regional opportunity is for terminal master's degrees in high-demand technology fields such as cybersecurity, data analytics, and health informatics. The Ritchie School will expand its accelerated, competitively-priced, industry-connected Masters offerings in computer science and engineering to help meet this exploding need while delivering positive results to the School's bottom line which can substantially reduce the School's need for philanthropic scholarship finance.

Strengthening research capability will require not only adding capability but delivering throughout at the highest standards. Implementing new terminal master's degrees will mean executing new types of programs, from inception through maturity, in an extremely effective and efficient manner. Accelerating undergraduate experiential excellence can build on the many good things done today, but will require additional focus, research, and implementation excellence.

The Ritchie School will move *forward faster* by making critical investments today in the highly relevant research and education programs that will advance healthy global citizens in a smart sustainable world.

2022: A LOOK AHEAD

By 2022, the Ritchie School will become known as an innovative jewel of a school in engineering and computer science that has achieved the following.

- 1. 50% of all undergraduate students will be students of color**
- 2. 50% of all undergraduate students will be women**
- 3. 20% of all undergraduate students will be first-generation college students**
- 4. The proportion of DU undergraduates majoring in Engineering and Computer Science will more than double, to 25% of the undergraduate population**
- 5. More than triple research funding in the unit with a strategic focus on:**

Artificial Intelligence | Biomechanics | Cyberphysical Security | Robotics | Smart Cities

- 6. Triple the number of PhD graduates in 10 years**
- 7. Professional Masters programs will generate over \$19 million in revenue per year**
- 8. Ranked by US News and World Report in Graduate Engineering and Graduate Computer Science**
- 9. Lead five critical University-wide initiatives**

- **Project X-ITE** – The Ritchie School is staking out new ground at the intersection of innovation, technology and entrepreneurship across the University of Denver campus. We will lead this project to fully scaled growth as we forge new paths for entrepreneurship, creation and collaboration for our students and faculty and the entire campus.
- **Institute on Disruptive Innovation** – DU has the unique breadth and depth of capabilities to become a global leader in understanding the implications of the accelerating tech-driven innovations disrupting our traditional economic, political, and social institutions. On topics ranging from the implication of unmanned vehicles for smart cities to technology disrupting the future of the professions (automation), DU's rare collection of legal, international, business, technical, and social expertise can position the University as a primary global platform for investigating and communicating all the implications, from policy through business, of the digitalizing world. A number of trustees have expressed strong interest in this initiative.
- **Digital Literacy** – DU should guarantee that every incoming student will graduate as a digitally literate citizen of the world.
- **E-STEAM** – the Ritchie Faculty feel that the journey to achieve the unit's diversity and inclusive excellence goals will create a center of excellence that can be adopted outside the unit and the University – not only in STEM fields but more broadly.
- **Multi-Modal, Multi-Discipline Professional Master's Degrees** – While the strategic plan focuses on residential Professional Masters to be taught by Ritchie School faculty, the best competitive position for DU would be to offer these and more both online and residentially to both working professionals and those taking time-off from work, on a multi-discipline basis.

2017: A CRITICAL JUNCTURE FOR THE RITCHIE SCHOOL

This is an exciting time for the Ritchie School of Engineering & Computer Science. The School is experiencing a new beginning embodied by its new building, programs and deans. This new beginning presents two future growth choices for the school: strategic growth or nominal growth.

STRATEGIC GROWTH

This option is bold, audacious, strategically focused, and fully supports the University's transformation embodied in the IMPACT 2025 Strategic Plan. It envisions a School with new initiatives, faculty and facilities to fuel a school-wide focus for its diverse student body on the global challenges of our time. Faculty would achieve more in the classroom and in the lab as they attract more grants to fund more exciting research at scale. In total, the Plan will see the number of undergraduate students in Ritchie School courses and majors more than double over the next five years, consistent with the experience other research-oriented liberal arts private universities have seen in the past decade.

Investing in this option will position the University of Denver (DU) as a global innovation leader in technology higher education. Achieving it will require a significant investment of time, resources and focus over the next five years from the School and the University. More specifically the strategy calls for investments in the following:

Scholarship support. While programmatic changes will make the undergraduate program more attractive and assist the school in attracting and retaining underrepresented groups and women, data on the School's Ritchie Scholars program and comparable programs make clear that significant scholarship support will be required over the next five years. The School will focus on specifying the required funding during the first quarter of calendar 2017 as much of the financial need may be provided by net contributions from the new professional masters offerings.

Space. The School will need more space as it grows, whether at Strategic or Nominal rates. The specific requirements will be specified during the first quarter of calendar 2017, but current estimates are for an increase of 35,000 square feet by 2022, about twice the additional space required under the Nominal case.

Faculty and initiative support. While the net operating investment required is relatively modest given the ramp-up in the professional masters and its related revenue, the faculty investments will be strengthened by more permanent support in the five strategic research clusters supporting the two Global Goals as well as diversity and engineering education modernization. The school would grow to 95 total faculty in 2022, compared to 54 for Nominal Growth.

NOMINAL GROWTH

The second option represents a continuation of the school's historical focus and performance (correcting for the impact of the Ritchie Scholars' program). Even growth at modest levels will require an investment in facilities and faculty since the School is at capacity now. This scenario is essentially 'business as usual', with limited changes to teaching or scholarship. Without those changes, the School will not be able to attract the quality or diversity of undergraduate students and will see continued declines in its graduate revenue and scholarship. The Ritchie School can survive, but will not be transformed.

Technological advances are critical to the next era of innovations for healthy, global citizens in a smart, sustainable world. Imagine Ritchie School faculty and students working together to.....

Ensure privacy of personal data on the cloud

Improve patient treatment using data science to streamline clinic processes

Use gaming to address gender equality in computer science and engineering education

Create the next gen intelligent electricity system using high temperature materials

Create a more accurate monitoring device for use in your health care

Use our understanding of the mechanics of human tissue to improve the next generation of health devices

Create a sensor that can control a prosthesis

Advance solutions to nervous system disorders by reverse engineering the brain

Design personalized online learning systems with artificial intelligence

Explore affordable energy storage solutions

Invent new miniaturization solutions to monitor water and air quality

Optimize the deployment of solar energy systems to lessen dependence on fossil fuels

Create autonomous systems to control street lights and traffic control

Invent the next generation of unmanned vehicle systems to monitor traffic congestion

Develop service robots to aid children with special needs

Create maintenance-free designs using imbedded sensors

Enhance public safety through sensor networks

Develop transmission infrastructure for publicly owned utility companies

Strategic Plan 2022

Daniel Felix Ritchie School of Engineering & Computer Science

Forward. Faster: A New Era for the Ritchie School

When the Ritchie School for Engineering & Computer Science (RSECS) embarked on an agile strategic planning process in Fall 2016, it was motivated by several converging factors. First, the school was moving into a wonderful new building designed to bring faculty and students from computer science and engineering together under one roof. The building and grounds were intended to spark collaboration and creative thinking around *next era* approaches to new and long standing challenges.

The second realization centered on the outstanding work of the faculty. The ground-breaking research and modern approaches to teaching already underway illustrated the untapped potential for excellence at scale in both, and the even greater potential for synergies across the two. The third converging factor was new leadership in the Dean's office that complement existing faculty leadership. Their experiences in industry and research forged a mutual belief that relevance in higher education is increasingly shaped by changes in the external environment, some of which are revolutionary in scale and impact. This was especially true in computer science and engineering, where the revolutionary and often disruptive nature of technological advances had an increasingly powerful impact on individual lives, societies and the planet.

Lastly, strategic planning was inspired by the need to move forward faster. Quite simply, if the School were to scale its research and teaching innovations beginning in the Fall 2017 academic year it had to act quickly to achieve its vision and actively support implementation of the University's IMPACT 2025 Strategic Plan.

This strategic plan considered the trends and changes in the external environment with the greatest potential to shape strategic direction. As the Ritchie School faculty and staff scanned the external environment, and considered internal strengths, a set of notable trends emerged as strategically significant for next five years. Individually and collectively, these factors will define relevance for technology higher education. The resulting Plan is an integrated whole requiring delivery on all the components in parallel.

Diversity and inclusive excellence. America is becoming more and more diverse, at accelerating rates. According to the [Pew Research Center](#), "Americans are more racially and ethnically diverse than in the past, and the U.S. is projected to be even more diverse in the coming decades. By 2055, the U.S. will not have a single racial or ethnic majority. Much of this change has been (and will be) driven by immigration." The Center further estimates that by 2050, 29% of the population will be Hispanic, up from 14% in 2005. Asians are also expected to increase from 5% to 9% of the US population. It is also expected that by 2050 19% of Americans will be foreign born, up from 15% in 2005.

While America has become more diverse, science, technology, engineering and math (STEM) educators and industries have not adapted quickly enough to meet the needs of the changing marketplace. Across the country, higher education institutions in STEM are focusing increasingly on the pipeline of underserved students, and domestic diversity more specifically. This focus is particularly critical to

addressing local income inequities, specifically in regions like the Front Range, where imported, credentialed talent has received the bulk of the area's increase in wealth. Federal grants are increasingly available to address these issues; both the University of Mississippi (Ole Miss) and Community College of Denver (CCD) have won federal grant awards in this area. Additionally, the private sector is teaming with higher education to fill the gap. The [American Talent Initiative](#), a new collaborative effort of universities led by the Bloomberg Philanthropies, aims to enroll more students from modest backgrounds at prestigious campuses with the proven ability to open doors to successful careers.

"Colorado companies are ideally positioned to take advantage of the rapid growth in science, technology, engineering, and math (STEM) industries across the nation. While the demand for STEM talent grows, the supply of STEM graduates is not keeping pace with the needs of companies."

Gender Equity in Colorado's STEM Industries, The Women's Foundation of Colorado

Industry is clamoring for this diverse and talented workforce to fill entry-level and managerial positions. According to the 2016 report on [Gender Equity in Colorado's STEM Industries](#) by The Women's Foundation of Colorado, "while there have been significant gains in the proportion of women who work in the biological sciences, there has actually been a decline in the proportion of women who work in the computing field over the last twenty-five years, and only slight gains in the proportion of women in engineering occupations" as tracked by the National Science Foundation.

Grand challenges. Research indicates that the best way to attract and retain underrepresented groups in STEM fields is to 'change the narrative', and both talk about and provide integrated experiential education explicitly addressing the great societal missions that these fields assist rather than traditional majors and fields of work. The School has adopted two Global Goals that reflect these goals and its strengths, to **Develop and Inspire Healthy Global Citizens** and to **Create a Smart, Sustainable World**.

The National Academy of Engineering moved to the Grand Challenges rubric after convening a group of leading technical thinkers to identify the "grand challenges and opportunities for engineering facing those born at the dawn of this new century" at the request of the National Science Foundation in 2008. That has led to the creation of a Grand Challenges Scholars program designed to "prepare students to be the generation that solves the grand challenges facing society in this century." (source: [NAE Grand Challenges](#))

The United Nations has identified [17 sustainable development goals](#) to drive their 2030 Agenda for Sustainable Development. Similarly, the American Academy of Social Work & Social Welfare has identified [12 grand challenges of social work](#).

The undergraduate experience. Today's undergraduate student expects project-based and real-world learning experiences in the classroom and outside. Likewise, employers seek to hire graduates with real-world experience and look for demonstrated team-based project experience. When engineering concepts and principles are brought to life through real-world problem solving and community service, enrollment and retention of domestically diverse students increases, as reported by the [U.S. News & World Report](#).

While projected [enrollment declines](#) are a pressing concern for university leaders presidents and leaders nationally, the increased enrollment in engineering undergraduate education is a bright spot. The Student Clearinghouse Research Center recently reported that "the number of students enrolled in an engineering

major jumped 4% between 2015 and 2016,” compared with “a drop of more than 3% in students majoring in history and English and a drop of 6.1% in students majoring in foreign languages, literatures and linguistics.” It appears that undergraduates (and their parents) are responding to concerns about the ROI for higher education and a challenging job market they are discovering that careers in technology can merge purpose and passion.

Professional master's degrees. Increasingly, working professionals are seeking terminal master's degrees in high-demand technology fields as they seek to advance or change careers. This degree option has become increasingly popular as it helps address the growing talent shortage in computer science and engineering-related careers in the United States and globally. In 2015 when the White House launched its Tech Hire Initiative, it was estimated that there were 500,000 open information technology jobs in the United States. Further, by 2020, the U.S. is projected to have 1.4 million computer specialist job openings according to the U.S. Department of Labor. These projections further show that universities are not likely to produce enough qualified graduates to fill even 30% of these jobs.

"Across the next decade, master's degrees are projected to grow far faster than degrees at any other level. By 2022, experts predict, master's degrees will account for nearly a third of all degrees awarded ... the fastest growth lies in master's programs designed for new and rapidly changing niche fields, such as cybersecurity, data analytics, and health informatics."

Understanding the Changing Market for Professional Master's Programs: An Introduction for Deans and Other Academic Leaders, Academic Affairs Forum

The Ritchie School is uniquely positioned to meet the extraordinary area demand for technology professionals. Colorado continues to thrive, with technology as a driver. The Milken Institute issued a report ranking Colorado #2 on its State Technology and Science Index, a measure of the state's innovation pipeline. The relatively lower density of higher education institutions in the area (compared to for example the Boston area) gives DU a unique competitive opportunity in this rapidly growing category.

Technology research. Technology plays a fundamental role in defining how we connect to each other, from communications through commerce, and in providing solutions to the world's greatest challenges. The pace of technological innovation is accelerating and disrupting every traditional human enterprise. Discoveries in foundational engineering and computer science disciplines are creating billion dollar industries overnight and rapidly displacing traditional institutions globally.

For example, fundamental research in Artificial Intelligence (AI) is driving the technologies that will change the world in the next decade and beyond. From self-driving cars to personal assistants, the potential uses for AI techniques are growing quickly. This has been recognized nationally, with federal strategic plans for AI recommending that funding be doubled over the next few years. The private sector is also embracing the potential of AI, with large AI research groups at companies such as Google, Microsoft, and many others.

The internet is an essential tool for communication, commerce, and monitoring, with individuals, businesses, and governments relying on safe and reliable access to a broad array of services, including things like civil infrastructure maintenance, population health monitoring, and business process

execution. Projections are for 30 billion devices connected to the Internet by 2020 (the ‘internet of things’). However, the connectivity driving innovation creates profound cyber-insecurity.

Technological advances are also shaping healthcare in profound ways. Current directions in health are toward personalized medicine and health monitoring technologies. Personalized medicine involves the creation of custom treatment plans or implants, while health monitoring, with devices like Fitbit or Apple Health, provides access to new levels of patient data and opportunities for feedback. As the population ages, the demand for biomechanical and bio-informational enhancements is outpacing innovation.

Finally, the world is urbanizing. According to the World Health Organization, urban populations will increase to 70% of the total population worldwide by 2050. This significant shift demands a more intelligent and better planned use of available resources of all types in urban environments, which has resulted in development of the concept of the Smart City. A Smart City is defined as a city that monitors and integrates conditions of all of its critical infrastructures for better optimizing its resources, planning its preventive maintenance activities, and monitoring security aspects, while maximizing services to its citizens (U.S. Office of Scientific and Technical Information). More broadly, smart cities are the harbingers for trends in roboticization, autonomous vehicles, enhanced aging, and the sharing economy. Cities across the globe are investing more time and effort into transforming themselves into the Smart Cities of the future. Denver is at the forefront.

IN SUMMARY

This is an exciting time for the Ritchie School. There is increasing demand for engineering and computer science education, and with that demand, an increasing need to graduate diverse students ready to make a difference for their employers and communities. There is also growing recognition that technology-based solutions are the foundation to a better society and better lives. More and more those solutions are developed at the intersection between engineering and computer science and fields such as business, social work, and international affairs.

As highlighted in the Executive Summary, the Ritchie School has two distinct paths ahead of it. One path pursues nominal growth that continues the historic growth rate, scale and quality across research and education (correcting for the one-time impact of the Ritchie Scholars’ program). The second option is transformational – the pursuit of focused and bold strategic growth. This option depends upon successful execution across all elements, from undergraduate excellence through the Masters and research efforts.

The Ritchie School can play a more significant role as a platform in one of the most innovative regions in the world in creating the knowledge bridges and talented workforce that will profoundly impact the future of human life in a smart, sustainable world. This necessitates bold strategic growth beginning in 2017.

On the next pages of this plan the School’s mission, vision, values, strategic objectives and outcomes are presented with a high-level expression of the financial investment and revenue potential under Strategic Growth. This plan is supplemented by detailed plans created by faculty and staff for Ratings and Rankings, Inclusive Excellence, Undergraduate Excellence, Professional Master’s Degree Program and Research (See Appendices F through J).

The School is indebted to its faculty and staff for their bold aspirations and to the Amplify Advisory Committee members who have reviewed and are advising the School on Strategic Plan implementation (See Appendices A and B).

Mission

*Advancing technical and scientific knowledge and capabilities to improve quality of life
for our global society*

Vision

*We are a diverse learning and teaching community discovering creative solutions for
healthy, global citizens living in a smart, sustainable world*

Values

We believe:

- Students are the center of our academic programs
- Students gain deeper knowledge through experiential learning
- Inclusive excellence is essential to tapping into diverse talents, ways of thinking and working together
- Collaboration across disciplines, boundaries and fields can lead to breakthroughs and innovation
- Continuous innovation is essential to teaching and research
- Creative thinking is fueled by an inquisitive nature and a quest for discovery

Strategic Objectives

1. Instill a culture of **inclusive excellence** and **more than double** the percentage of students who come from diverse backgrounds
2. Focus research and education programs to address two relevant, real-world **Global Goals**
3. Modernize the **undergraduate program**
4. Grow the **research enterprise**
5. Build a suite of highly relevant **professional master's degrees**
6. Improve **brand and reputation** domestically and abroad

OUTCOMES

By 2022, the Ritchie School will become known as an innovative jewel of a school in engineering and computer science that has achieved the following.

1. 50% of all undergraduate students will be students of color
2. 50% of all undergraduate students will be women
3. 20% of all undergraduate students will be first-generation college students
4. The proportion of DU undergraduates majoring in Engineering and Computer Science will more than double, to 25% of the undergraduate population
5. Triple research funding in the unit (note; this depends on tenure vs. teaching-track faculty ratios) with a strategic focus on:
Artificial Intelligence | Biomechanics | Cyberphysical Security | Robotics | Smart Cities
6. Triple the number of PhD graduates in 10 years
7. Professional Masters programs will generate over \$19 million in revenue per year
8. Ranked by US News and World Report in Graduate Engineering and Graduate Computer Science
9. Lead five critical University-wide initiatives

Investing in Excellence

Two growth scenarios were explored for the Ritchie School – Nominal Growth and Strategic Growth. The financial impact and investment requirement for each are presented here accompanied by four years of historical data, the current estimate, and a five-year projection.

Exhibit 1. Revenue, Expense and Net Comparison – Historic and Projected

	FY13 Historical	FY14 Historical	FY15 Historical	FY16 Historical	FY17 Estimate	FY18 Projected	FY19 Projected	FY20 Projected	FY21 Projected	FY22 Projected
Nominal Revenue	\$8,244,223	\$8,785,023	\$10,539,993	\$11,989,567	\$11,837,208	\$13,972,332	\$17,315,951	\$19,269,513	\$20,786,279	\$22,346,995
Expense	\$6,238,133	\$6,962,250	\$7,768,932	\$8,594,216	\$9,101,459	\$11,465,337	\$12,385,387	\$13,193,281	\$13,597,311	\$14,604,131
Nominal Net Operating Income	\$2,006,090	\$1,822,773	\$2,771,061	\$3,395,351	\$2,735,749	\$2,506,995	\$4,930,564	\$6,076,232	\$7,188,968	\$7,742,864
Strategic Revenue	\$8,244,223	\$8,785,023	\$10,539,993	\$11,989,567	\$11,837,208	\$13,972,332	\$21,783,784	\$31,190,975	\$39,055,007	\$47,507,432
Expense	\$6,238,133	\$6,962,250	\$7,768,932	\$8,594,216	\$9,101,459	\$14,052,540	\$19,900,327	\$21,015,740	\$25,049,181	\$28,147,805
Strategic Net Operating Income	\$2,006,090	\$1,822,773	\$2,771,061	\$3,395,351	\$2,735,749	-\$80,208	\$1,883,457	\$10,175,235	\$14,005,826	\$19,359,627

The chart below illustrates the difference in projected revenue between the two growth options. It is projected that Strategic Growth will generate \$47.5 million in FY '22 revenue compared to \$22.3 million under the Nominal Growth scenario. The difference in revenue is fueled by a combination of growth in the undergraduate and professional (terminal) master's programs, and the research enterprise. Note that these forecasts do not include the positive impact of increased research funding through the unit.

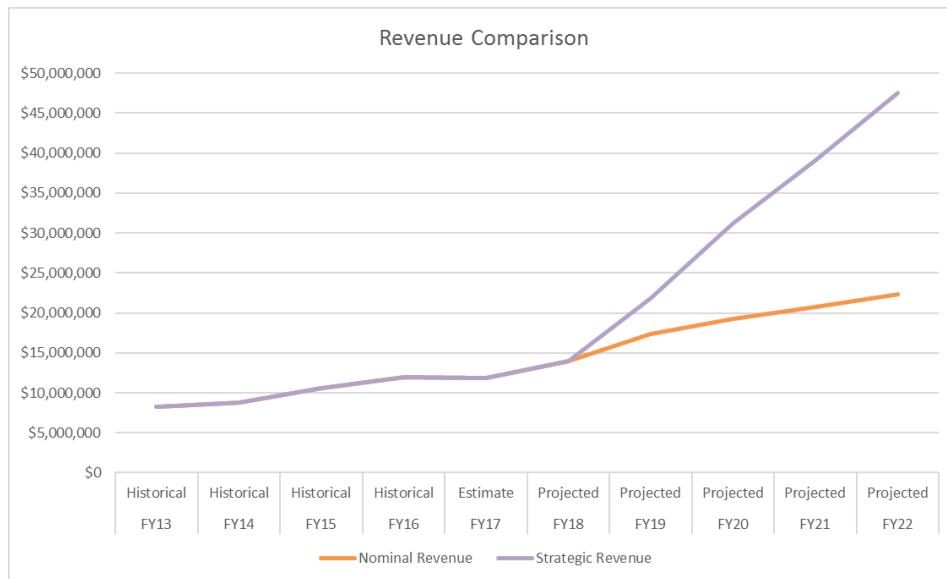


Exhibit 2. Revenue Comparison for Nominal and Strategic Growth, Including Historical

On the next page the difference in net operating contribution is examined more closely.

The Strategic Plan has many components, all of which work in concert to deliver outcomes by 2022. The net investment impact of the plan reflects increased expenditures for inclusive excellence, undergraduate education modernization and accelerated expenditures for research enterprise, including the hiring of more tenured faculty and associated start-up packages, compared to the Nominal Scenario. Profitable growth in the Professional Masters Programs quickly generates more than enough net revenue to compensate for these investments. The Ritchie School is forecast to generate more than twice as much net revenue for DU by 2022 under the Strategic vs. Nominal plan.

The Plan's Strategic Growth scenario calls for \$5.6 million more investment over the next two years, but will generate \$11 million more net contribution over the following two years than the Nominal Growth plan – with increasing returns thereafter. These figures do not account for the increased research funding contribution from the unit under the Strategic Growth scenario.

As illustrated in Exhibit 3 below, the difference in net contribution between the two scenarios is \$2.6 million less for Strategic in FY '18 and \$3 million less in FY '19. In FY '20 the net contribution is \$4 million more for Strategic than Nominal and \$6.9 million more in FY '21.

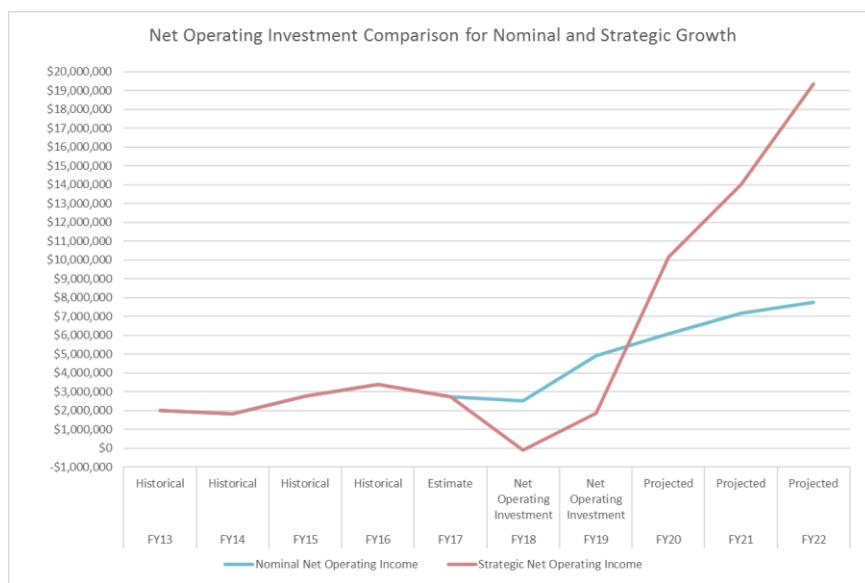


Exhibit 3. Net Operating Investment Comparison for Nominal and Strategic Growth, Including Historical

A more detailed financial plan can be found in Appendix C.

Strategic Objectives

INCLUSIVE EXCELLENCE

Strategic Objective: Instill a culture of inclusive excellence and more than double the percentage of undergraduate students who come from diverse backgrounds

The School's most important and difficult challenge is the creation of an inclusive culture: in the classroom, in faculty meetings, in research meetings, and outside the classroom among students and staff. The significance of this challenge is one the School embraces and recognizes as it must be addressed if it is to achieve its other bold aims. The current problem is exacerbated by the lack of role models, domestically diverse faculty and graduate teaching assistants, as well as the lack of knowledge of inclusive cultural interactions. The current baseline composition for Fall 216 undergraduate students is: 21.3% women, 23.0% are students of color, and 16.4% first generation college students out of 575 full-time students.

By the end of FY '22 the Ritchie School will serve as an exemplar of inclusive excellence for the University of Denver and technology higher education nationally. At least 50% of students will be female and at least 50% will be students of color. The Ritchie School also commits to increasing the percentage of 1st generation students to at least 20% of all students.

As illustrated in the visual to the right, under the Strategic Growth option the Ritchie School expects to serve 1,400 total undergraduate students in FY '22 (Fall 2021), and those students will include more students of color, women students of color, and women.

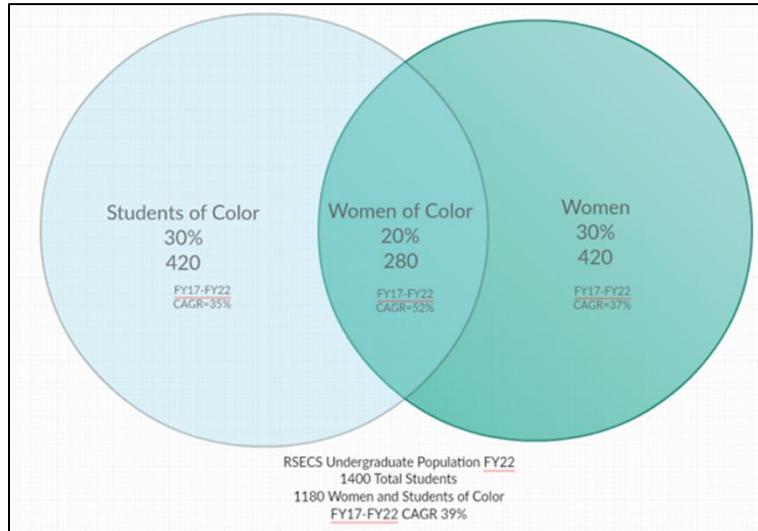


Exhibit 4. FY '22 Undergraduate Student Composition with Females and Students of Color at 50% Each

By creating an inclusive and welcoming culture, the Ritchie School will have a competitive advantage over other institutions that fail to act in this area - a problem that will become exacerbated as the national demographics continue to shift. The School will also help industry meet its primary goals – a more diverse, broadly experienced, and inclusive workforce.

The path to inclusive excellence is tightly connected to the modernization initiatives in undergraduate education described below. The School is launching a faculty-driven, school-wide initiative to embrace inclusive excellence and modern teaching pedagogies throughout the undergraduate curriculum. Given its small size and recognition that culture change is paramount to achieving the goals of broadened participation in a modernized undergraduate curriculum, RSECS is establishing a single team to achieve these interrelated strategic aims. The team will be responsible for implementing the inclusive excellence and undergraduate excellence strategic plans with strong connections to research through the new Global Goals framework described below. The team will be comprised of nine forward thinking faculty with the passion and sense of moral imperative to change the curriculum and who view everything through a lens of inclusive excellence. They will be supplemented by visiting faculty with expertise in inclusive excellence and modern pedagogies.

GLOBAL GOALS

Strategic Objective: Focus research and education programs to address two relevant, real-world Global Goals

As the foundation for a research-based liberal arts University, Ritchie School faculty and students will continue to be at the forefront of the creation of new knowledge, approaches and inventions. Knowledge is increasingly created at the intersection of disciplines and across traditional institutional boundaries. At the same time, many of the undergraduates that DU attracts self-define as innovators and entrepreneurs.

The Ritchie School will become a regional STEM leader in teaching and research from undergraduate through the PhD program by modernizing and strengthening its offerings around two Global Goals: **Develop and Inspire Healthy, Global Citizens** and **Build a Smart, Sustainable World**.

These Global Goals will inform the School's incremental investment in research capability across five areas: Artificial Intelligence, Biomechanics, Cyberphysical Security, Robotics, and Smart Cities.

These Goals relate directly to both the National Academy of Engineering's (NAE) [Grand Challenges](#) as well as the United Nations' [Sustainable Development Goals](#). Similarly, the American Academy of Social Work & Social Welfare has identified [Social Work Grand Challenges](#), some of which benefit from a technology solution.

The Ritchie School can make a unique and lasting contribution to each of these highly relevant goals, beginning in the research labs and continuing through the educational programs and extracurricular activities.

Develop and Inspire Healthy Global Citizens

In an aging world augmented with increasingly autonomous and intelligent technology, the Ritchie School believes it has a responsibility to help develop and sustain a healthy, informed global citizenry. Engineering and computer science disciplines are at the forefront of developing solutions to ensure that the world's population lives longer, more productive, and more informed lives. The Ritchie School has conducted state-of-the-art research applying these disciplines to some of the most vital health challenges facing the world.

The world-renowned biomechanical research and engineering capability (Center for Orthopaedic Biomechanics) can create anything from catheters to joints through its fully integrated capabilities spanning sensor and computational modeling to device modelling and build. Faculty work on social robotics has helped tackle vital health and care challenges faced by the aging and health-challenged populations. The School's computer scientists have applied game theory and construction to a range of

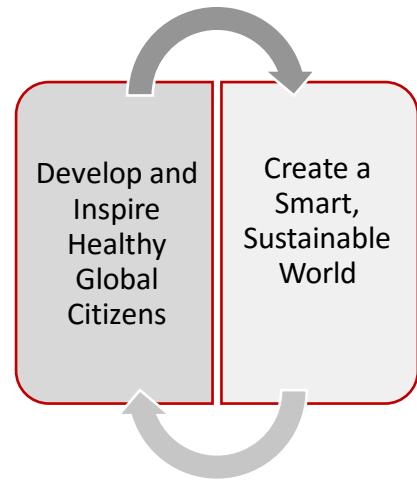


Exhibit 5. Ritchie School Global Goals

individual educational development challenges. The Knoebel Institute on Healthy Aging opened earlier this year as a collaborative hub for solutions on complex aging issues. These capabilities, along with many others, represent the strong foundation upon which RSECS will continue to innovate to help empower a healthier, more engaged citizenry and teach the next generation of global civic leaders.

Create Smart, More Sustainable World

The world has become increasingly connected with smart sensors communicating all around us all the time. By 2020, 20 billion sensors will be constantly communicating and managing their roles on an increasingly autonomous basis. This connectivity is fundamental to the drive toward a more sustainable world, as it allows for smart management of the energy grid, autonomous vehicles, distributed financial intelligence systems, and the automation of historically mundane and dangerous work, among many other innovations. Security has become a paramount concern for this hyper-connected and communicating world.

The Ritchie School is at the nexus of this connectivity, developing creative solutions in fields ranging from artificial intelligence to cybersecurity, robotics, smart grids, aerosols, and climate change, and through our applied materials work on the energy grid with the NSF HVT Center. By investing in its Smart Cities, Smart Grid, robotics, artificial intelligence and cybersecurity capabilities—a unique cross-section of solutions—The Ritchie School is driving toward a smarter, more sustainable world.

UNDERGRADUATE EXPERIENCE

Strategic Objective: Modernize the undergraduate program

The Ritchie School will excel at preparing graduates to thrive in a dynamic and global environment. These students will be more diverse than any previous class; will have the theoretical foundation and technical skills required to be successful in an ever-changing workplace; will sharpen their ability to work in multi-disciplinary teams to solve complex problems; and will be prepared for advanced graduate work or a career in their field of choice.

A survey of students was conducted in November 2016 to provide data on the School's competitive set and unique attributes from the perspective of current students (See Appendix D). The survey revealed that the decision to major in engineering or computer science appears to be well-formed as many students reported an interest in the fields before applying to college. When asked about the attributes that made them decide to attend DU, students noted the size of the school, opportunities to study abroad, the Learning Effectiveness Program and overall institutional reputation. Not surprisingly, the appeal of the new engineering facility was mentioned.

Current Ritchie School students mentioned that a few liberal arts aspects of DU were attractive to them, such as small class sizes, close relationships with professors and ability to take humanities and business coursework outside of the major.

The student survey also revealed the top five largest competitors are the University of Colorado Boulder, Colorado State University, Colorado School of Mines, California Polytechnic State University and University of Washington Seattle. Given its strong in-state competition, the School can make the most of

its liberal arts attributes listed above, its Denver location, and new strategic differentiation designed around Global Goals and a modernized inclusive program.

Because students have a vast number of options for an undergraduate education, the Ritchie School seeks to attract students who want a unique experience. As a small, private university (and one of the few in the Rocky Mountain region with both engineering and computer science programs), DU can amplify its student-focused undergraduate experience by providing each student with an education aligned with their passions and sense of purpose, both during their time at DU and when moving into the job market or advanced graduate education.

The School is adopting the following set of guiding principles for its undergraduate program.

Guiding Principles for a Ritchie School Undergraduate Education

1. All students participate in at least one (1) project-oriented, team-based, customer / product / service-driven experiential, inclusive, and public-good oriented course each year.
2. All students engage in at least one (1) extra-curricular experience each year.
3. All students have at least one internship or Co-Op before they graduate.
4. All students have a Grand Challenges experience.
5. Faculty commit to a high level of engagement with students inside and outside the classroom.
6. All students are assessed annually against the Ritchie School graduate characteristics.

As noted above, the School is adopting a Grand Challenges program centered around the two Global Goals. This program will grow over five years to engage all undergraduate students. The program will expand each year as the incoming class of Fall 2017 advances in their education.

By Fall 2021 every freshman will have a Grand Challenge path to graduation. This aligns with DU's Grand Challenges program outlined in Impact 2025. Beginning in Fall 2017, RSECS will adopt the NAE Grand Challenges Scholars Program (GCSP) with a cohort of 20. A cohort will be added each year to create a full program of 80 scholars. This program incorporates five components: hands-on project or research experience, interdisciplinary curriculum, entrepreneurship, global dimension, and service learning.

The Strategic Growth scenario illustrated here assumes an increase in enrollment of 12% for Fall 2018 and accelerated growth thereafter as the modernized curriculum and inclusive excellence programs are implemented. This will result in more than doubling the size of the freshman class in five years from 575 in Fall 2016 to 1,400 by Fall 2021.

The School also explored a Nominal Growth scenario with 7% annual growth, which is less than the average

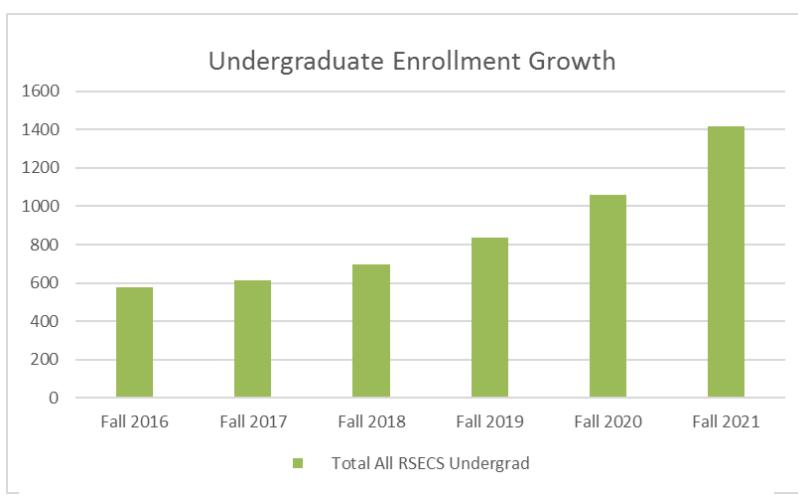


Exhibit 6. Strategic Growth of Undergraduate Enrollment

growth over the last five years of 17.7%, fueled in part by the Ritchie Scholarship Program.

To maintain the current student-faculty ratio of 15:1 the number of faculty will need to increase to support Nominal or Strategic Growth. That growth is beyond the 19 new faculty hires required to support the research enterprise. For additional information on faculty growth please see Appendix E.

Under Strategic Growth, the Ritchie School will serve 25% of total undergraduate enrollment of DU's 5,630 total at the end of five years. This overall rate of growth is realistic given the natural rate already occurring at the School, recent national trends, and the School's relevant strategic positioning. For example, according to the [National Student Research Center](#), "the number of students enrolled in an engineering major jumped 4% between 2015 and 2016."

RESEARCH ENTERPRISE

Strategic Objective: Grow the research enterprise

The Ritchie School is at the forefront of inquiry and discovery to address significant societal goals locally, nationally and internationally – healthy global citizens living in a smart, sustainable world. Faculty have created a research enterprise with outsized results in highly relevant areas. They are dedicated to collaborative, inclusive discovery and knowledge creation. Additionally, they work across disciplines within the school around the DU campus and partner with industry, government, and universities around the globe. The School is an incubator of knowledge creation serving the public good.

The research enterprise will focus intentionally to move the needle on its Global Goals as the School builds upon the capabilities of existing faculty. A recent audit of the Ritchie School's strengths and market trends identified five areas with significant strategic potential for impact across the Global Goals. Research will also inform teaching across the undergraduate and graduate programs aligned with the Global Goals. This focus will aid the School in advancing its mission and vision and the University's IMPACT 2025 Strategic Plan.

The Ritchie School will build research capability in five areas: Artificial Intelligence, Biomechanics, Cyberphysical Security, Robotics, and Smart Cities. Each of these areas is strategically important to industry, government and advancing the public good. Individually and collectively they are expected to yield impactful new discoveries and advance existing scholarship across multiple fields. We expect to hire 19 faculty to support the following areas, growing from 27 tenured faculty currently.

- **Artificial Intelligence (AI)** – Fundamental research in AI is driving the technologies that will change the world in the next decade and beyond. From self-driving cars to personal assistants, the potential uses for AI techniques are growing quickly.
- **Biomechanics** – Increasingly, engineering solutions can be found to major health problems and other conditions that limit quality of life. The School has had a robust orthopaedic biomechanic cluster for some time. Society has only begun to see the positive impacts that sensors, smart devices and wearable technologies, among others, can make on people's lives.
- **Cyberphysical Security (CPS)** – The internet is an essential tool for communication, commerce, and monitoring for individuals and businesses in areas such as civil infrastructure maintenance, population

health monitoring, and business process execution. However, the very connectivity that enables these innovative applications also exposes them to tampering and misuse.

- **Robotics** – The field of robotics is witnessing exponential growth worldwide and will continue to be at the forefront of cutting edge technologies given the range of issues it can address. Ritchie School faculty focus on service robotics and unmanned systems that serve the public good.
- **Smart Cities** – The core strengths of the Ritchie School's Smart Cities research and development is in smart electricity grids, materials and structures, unmanned systems, and environment/climate. Smart City research has a cross-disciplinary nature, i.e., it goes beyond the limits of a department and school, is in line with National Academy of Engineering grand challenges and is aligned with National Science Foundation big ideas.

This strategic focus leverages:

- **Current research strengths** that are already developed, have garnered high visibility and demonstrated continuous success to date, but require additional investment in faculty hires and upgraded infrastructure to not only remain competitive, but to also be well-respected and well-recognized 'research differentiators' nationally and internationally;
- **On-going research** activities that are successful and have demonstrated great potential of growth, but require significant investment in new faculty hires and infrastructure to capitalize on existing talent and to create the required critical mass for sustainable success; and
- **Recent initiatives** where RSECS can be a major player and differentiator. These areas require major investment in human capital and resources, short- and long- term, to build credibility at the national level that will lead to recognition and success.

As a relatively small school, it is critically important that the School focus its research agenda around strategically relevant issues and capabilities. The School's highly relevant research expertise in games, software engineering, optimization, aerosol/climate, and neuro engineering will impact success in one or more of our selected growth areas and across the two Global Goals.

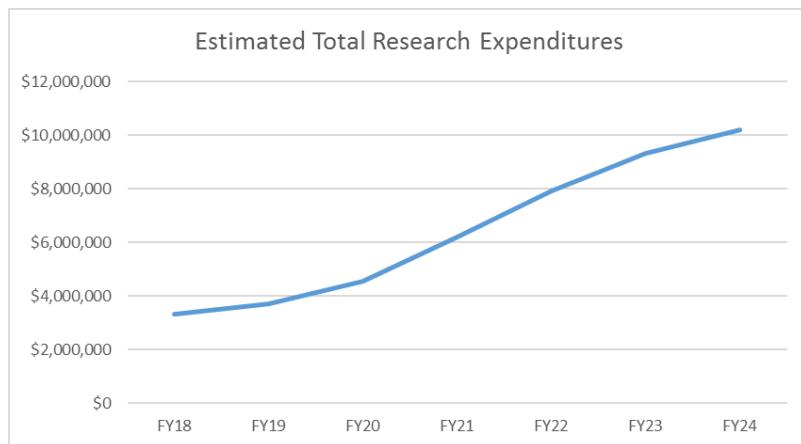
Experience shows that bringing together faculty with complementary and overlapping expertise leads to highly successful and impactful, funded research and development. These strategic investments result in high-quality research expertise, laboratories and computational facilities. Over time the School envisions the development of new centers to recognize the continued strategic relevance of these knowledge creators.

As detailed in Appendix E, this Plan estimated total faculty size and balance of Tenure Track and Teaching for Strategic Growth. The size of the faculty will need to grow to serve the larger undergraduate and graduate programs, inclusive excellence and the research enterprise. Three scenarios were explored to better understand the options for the mix of Tenure Track and Teaching faculty to serve the School's strategic aims and Scenario 3, an average of the other two, was used to portray growth in this plan.

The addition of 19 strategic faculty hires is expected to more than double the research expenditures in the School from current levels. These investments will continue to pay off well beyond the five-year planning horizon as illustrated here. Current expenditures of \$2.8 million will grow to \$7.9 million by FY '22 and on to \$10.2 million by FY '24 through the addition of faculty in highly relevant areas and an increase in overall research productivity.

The average expenditure per faculty member is also expected to increase from approximately \$104,000 in FY '17 to \$141,000 in FY '22 and \$182,000 in FY '24.

This strategic focus on research will flow through with positive results for traditional graduate students. These students select their academic home based on faculty credentials, available labs and facilities, financial support and opportunities to launch successful careers. The School expects to increase the number of PhD students from 12 to 16 by FY '22 with continued growth to 55 by FY '27 (See Appendix E).



**Exhibit 7. Estimated Total Expected Research Expenditures
FY '17 – FY '24**

PROFESSIONAL MASTER'S DEGREES

Strategic Objective: Build a suite of highly relevant professional master's degrees

By leveraging Denver and Colorado's thriving innovation economy, the Ritchie School is well positioned to help alleviate the concerning talent shortages in engineering and computer science-related fields. Its new suite of accelerated Professional Master's degrees (PMDs) will prepare students to pursue careers in high demand. Of the top 25 occupations requiring a bachelor's degree in Colorado in 2014, five are in information technology (IT) and two in engineering, with all exhibiting positive projected growth rates between 1.9%-3.4% through 2024.

A liberal arts institution like the University of Denver provides unique advantages in that students will not only receive instruction in the technical foundations needed to be successful, but also learn how to think critically in any situation, ask the right questions and successfully work on diverse teams. These non-technical and experiential learning components differentiate the new suite of PMDs offered by RSECS from the multitude of educational offerings on the market. PMDs will be priced competitively with similar offerings locally.

Professional Master's Degrees will be comparable in quality and technical depth to the Master's degrees currently offered by the Ritchie School, but will focus on the experiential learning and skills needed to be successful professionally, rather than the independent research and scholarship emphasized in traditional two-year Masters programs.

The School has had continued success providing a range of terminal master's offerings to Lockheed Martin employees, who have indicated an expectation for increased demand in coming years. Additionally, the School recently launched a one-year, competitively priced MS in Cybersecurity. The new suite of degrees is designed to be completed in one academic year (nine months/three quarters) assuming prerequisite or "bridge" coursework is not required. PMDs will be offered throughout the academic year and students can anticipate a full schedule five days a week, including on-site work at industry partners. The intensive nature of these degrees requires that all students be in residence in Denver to complete coursework on campus and an internship onsite with an industry partner during all three academic quarters of the program. The School will also revise and extend its executive programs.

The initial list of new degrees includes:

Current degree program

Computer Science

- MS-Cyber Security

Proposed new degree programs

Computer Science

- MS-Data Science
- MS-Internet of Things
- MS-Web Development

Electrical and Computer Engineering

- MS-Financial Engineering
- *Materials and Mechanical Engineering*
- MS-Product Design

The School is also motivated to pursue this market opportunity as it can yield substantial financial support to fund other strategic objectives as shown below. Under Strategic Growth, the Ritchie School estimates five-year growth in student enrollment generating about a \$17 million contribution margin in the fifth year. For comparison, Nominal Growth assumes that only Cyber Security and Data Science degrees will be offered. Note that scale (depth and breadth of programs) is critical to market success in the professional masters category.

Exhibit 8. Strategic Growth of PMD Degree Offerings

Accelerated MS Degrees	FY18	FY19	FY20	FY21	FY22	Steady State
Cybersecurity	\$717,413	\$1,809,760	\$2,143,708	\$2,497,628	\$2,851,548	\$2,851,548
Data Science	\$515,173	\$1,658,080	\$2,143,708	\$2,497,628	\$2,851,548	\$2,851,548
Internet of Things		\$1,071,333	\$1,986,720	\$2,143,708	\$2,497,628	\$2,851,548
Web Applications		\$1,071,333	\$1,986,720	\$2,143,708	\$2,497,628	\$2,851,548
Robotics		\$1,071,333	\$1,986,720	\$2,143,708	\$2,497,628	\$2,851,548
Product Design			\$1,071,333	\$1,986,720	\$2,143,708	\$2,851,548
Financial Engineering			\$1,071,333	\$1,986,720	\$2,143,708	\$2,851,548
Degree Operating Revenue	\$1,232,586	\$6,681,839	\$12,390,242	\$15,399,820	\$17,483,396	\$19,960,836
Net Program Revenue	\$414,086	\$4,339,139	\$9,447,742	\$12,702,320	\$15,184,896	\$17,445,336

The PMD program can strengthen the School's business model by expanding contributed revenue to offset some of the investment required for other initiatives per the financial plan.

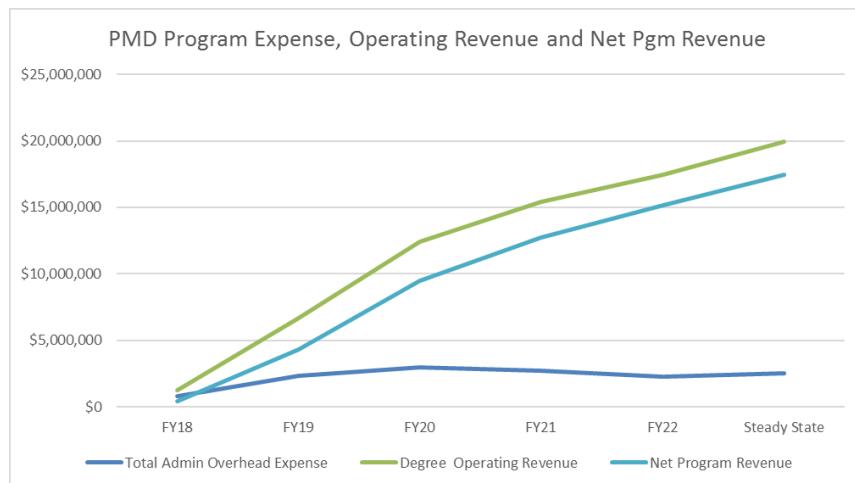


Exhibit 9. PMD Program Revenue and Expense under Strategic Growth

As illustrated in Exhibit 9 above, the Total Administrative Overhead Expense is expected to decrease slightly at Steady State when it is assumed that the marketing cost per student decreases as economies of scale, and market traction, are reached.

Additionally, there is also the potential to repackage and aggressively market RSECS's historical and existing one-year, academic, non-thesis degrees with strategic potential in Computer Science (3 degrees), Electrical Engineering (5 degrees), and Materials and Mechanical Engineering (6 degrees) as well as its industry program (cf. Lockheed, Martin).

As a first step in the professional masters strategic plan, RSECS will complete detailed planning in the first quarter of 2017 as well as launch a national search for a Professional Masters Executive Director. This planning will include more detailed and degree-specific market analysis and forecasting for professional master's degrees. The work will include market research to identify target market, program preferences, willingness to pay, demand forecasts and positioning relative to competitors.

RATINGS AND RANKINGS

Strategic Objective: Improve the School's brand and reputation domestically and abroad

The Ritchie School will improve its brand and reputation as evidenced by increased ratings and rankings. See Appendix F for the detailed strategy.

US News & World Report Rankings

Engineering

Undergraduate Overall Engineering - USNWR rankings for undergraduate engineering programs where the highest degree offered is as doctorate is based entirely on a survey of the deans of other ABET-accredited engineering programs.

Current Rank: #183 out of 205 (tied with Catholic, North Dakota State, South Dakota State, Florida Atlantic University, Tuskegee University, Western Michigan, University of Missouri Kansas City, University of North Dakota, University of Tennessee Chattanooga)

Current Percentile: 89th Percentile

2022 Target: Achieve a ranking in the 85th Percentile

Undergraduate Engineering Specialties - USNWR ranks undergraduate programs where the highest degree offered is a doctorate in the following specialties available at RSECS: Computer Engineering, Electrical Engineering, Materials Science, Mechanical Engineering. These rankings are based 100% on a survey of department chairs.

Current Rank: Rank not published

2022 Target: Use learnings from upcoming campaign to improve overall engineering undergraduate ranking to focus on specialty specific rankings in the next five-year period.

Graduate Overall Engineering - For overall graduate rankings, 40% of the ranking is based on reputation (survey of deans 25% and survey of employers 15%). For special rankings, 100% of the score is based on a survey of the deans.

Current Rank: Rank not published (bottom 25%)

Peer: 1.8/5

Recruiter: 2.3/5

2022 Target: Achieve a rank in the top 75% so we have a numerical ranking

Peer: 2.2/5

Recruiter: 2.8/5

Computer Science

Graduate Overall Computer Science - USNWR considers Computer Science under its Sciences Rankings. The overall rankings are based on surveys of deans and department chairs.

Current Rank: Rank not published (average score lower than 2.0)

2022 Target: Achieve a score of 2.0 to be numerically ranked

Other Rankings

Games Development Rankings Overview

Through the School's survey and informal conversations with undergraduates, it appears that many in the computer science department learned of the University of Denver because of its Games Development degree. Undergraduate degrees in Games Development are rare, and a point of differentiation for the DU and RSECS. Actively submitting data to rankings of Games Development programs will heighten RSECS's profile for students who are interested in Games Development.

Games Development Rankings Strategy

RSECS aims to be in the top 50% of the Games Development Rankings list the next time the lists are issued with our data included. Those lists include:

- Princeton Review - Princeton Review ranks the top 50 Game Design programs and is public about its methodology.
- SuccessfulStudent.org - Successful Student recently listed their top 57 Video Game Colleges (up from 27 in 2015).
- GameDesigning.org - GameDesigning.org listed the University of Denver as #49 in its top 50 Game Design Schools and Colleges, yet it doesn't appear that data specific to the Games Development program was actually submitted.

FACILITIES

The expected nominal growth in undergraduate enrollment will necessitate more space for the Ritchie School over the planning horizon. The Strategic Growth plan will require twice as much increased space. In parallel, the School also recognizes that the type of space needed to support a collaborative learning community will look different than it has historically. The shift to co-working environments and flexible spaces calls for a fresh look at the next era of space to meet the Ritchie School's Strategic Plan.

This Plan calls for an additional increase of approximately 17,500 square feet to support Nominal Growth over the next five years or 35,000 additional square feet (approximately) to support Strategic Growth. The initial cost estimates for a building like WeWork or Galvanize, priced at \$260/ft² including tenant finish, is \$4.6M (nominal) to \$13.8M (strategic). The Financial Plan in Appendix C includes more detailed space and cost estimates for Strategic and Nominal Growth.

A more robust financial analysis will be completed in early 2017 as the School engages in a feasibility study for space planning.

DU-WIDE INITIATIVES

The University of Denver is a research university, and knowledge creation is at the center of its mission. Advancing the University's mission and strategic transformative directions calls for new ways of cross-disciplinary work. The Ritchie School is uniquely positioned to play a leadership role in one or more of the following five University initiatives of strategic significance.

- **Project X-ITE** – The Ritchie School is staking out new ground at the intersection of innovation, technology and entrepreneurship across the University of Denver campus. We will lead this project to fully scaled growth as we forge new paths for entrepreneurship, creation and collaboration for our students and faculty and the entire campus.
- **Institute on Disruptive Innovation** – DU has the unique breadth and depth of capabilities to become a global leader in understanding the implications of the accelerating tech-driven innovations disrupting our traditional economic, political, and social institutions. On topics ranging from the implication of unmanned vehicles for smart cities to technology disrupting the future of the professions (automation), DU's rare collection of legal, international, business, technical, and social expertise can position the University as a primary global platform for investigating and communicating all the implications, from policy through business, of the digitalizing world. A number of trustees have expressed strong interest in this initiative.
- **Digital Literacy** – DU should guarantee that every incoming student will graduate as a digitally literate citizen of the world.
- **E-STEAM** – the Ritchie Faculty feel that the journey to achieve the unit's diversity and inclusive excellence goals will create a center of excellence that can be adopted outside the unit and the University – not only in STEM fields but more broadly.
- **Multi-Modal, Multi-Discipline Professional Master's Degrees** – While the strategic plan focuses on residential Professional Masters to be taught by Ritchie School faculty, the best competitive position for DU would be to offer these and more both online and residentially to both working professionals and those taking time-off from work, on a multi-discipline basis.

DU IMPACT 2025

The Ritchie School's strategic plan can support implementation of the University's Strategic Plan in the following clusters.

EXHIBIT 10. STRATEGIC PLAN ALIGNMENT

DU IMPACT Cluster/Initiative	Ritchie School Strategic Plan
<i>Designing and Developing Knowledge</i>	Create knowledge bridge pilots via our two Global Goals and RSECS digital literacy effort
<i>Faculty Talent, Excellence and Diversity</i>	Ritchie School's Inclusive Excellence Strategic Plan and faculty-driven structure can be a model for other units
<i>Knowledge Bridge Incubator</i> - Knoebel Institute for Healthy Aging	Actively support 2 of their 5 strategic goals: Engage in interdisciplinary research together; Engage in business development and innovation related to aging
<i>DU and Engagement with Denver & Region</i> - Project X-ITE	Integrate Project X-ITE into curricular and extracurricular activities to advance entrepreneurial approaches to Global Goals; serve as possible pilots or student-led efforts
<i>DU and the Public Good</i> - Collaboration for the Public Good - Denver Grand Challenges	Serve as a source of "found" pilots for Global Goals, NAE Grand Challenge Scholars and student-led efforts
<i>Preparing Students for Careers and Lives of Purpose</i>	Be a source of "found" pilots on employer-related efforts for our Internships and Co-Ops
<i>Enhancing and Expanding the Learning Environment</i> - International Education - Teaching, Learning Outcomes and Assessment (Undergraduate)	Participate in enhanced recruiting efforts at grad and undergrad levels; Expand partnership with Glasgow Serve as a pilot for our new teaching, learning outcomes and assessments for undergrads
<i>Enrollment and Financial Support for Undergraduate Students</i>	Expand Ritchie School Scholarship Program to attract more under-represented populations
<i>Sustainable DU</i>	Be a leader in advancing a "smart" DU through our Smart Cities research and Global Goal for a Smart, Sustainable World; DU could serve as a test bed or pilot for research and student projects

Appendix

- A. Strategic Planning Committee Members
- B. Amplify Advisory Committee Members
- C. 5-Year Financial Plan with:
 - Exploration of Strategic Growth and Nominal Growth
 - Space Plan
 - Scholarship Analysis
- D. Undergraduate Survey Findings
- E. Faculty Size and Composition under Strategic Growth
- F. Ratings and Rankings Strategy
- G. Inclusive Excellence Strategic Plan
- H. Undergraduate Excellence Strategic Plan
- I. Professional Master's Degree Strategic Plan
- J. Research Centers of Excellence Strategic Plan

* Additional background information used during strategic planning can be found on SharePoint.

Appendix A. Strategic Planning Committee

This strategic plan is a result of countless hours of committed work by Ritchie School faculty. They contributed through committees, conversations, research, and report writing. The School is indebted to their leadership and commitment to teaching and scholarship.

Faculty

1. Amin Khodaei
2. Bob Whitman
3. Breigh Roszelle
4. Chris GauthierDickey
5. Goncalo Fernandes Pereira Martins
6. Jason Roney
7. Kimon Valavanis
8. Margareta Stefanovic
9. Mario Lopez
10. Matthew Gordon
11. Matthew Rutherford
12. Mohammad Mahoor
13. Nathan Sturtevant
14. Paul Rullkoetter
15. Pete Laz
16. Ramki Thurimella
17. Ron DeLyser
18. Scott Leutenegger
19. Susanne Sherba
20. Yun-Bo Yi

Deans

21. JB Holston
22. Haluk Ogmen

Staff

23. Susan Bolton
24. Debra Mixon Mitchell
25. Amalia Phillips
26. Ashley Sherman
27. Betsy Hart
28. Nina Sharma
29. Paul Forsberg

The committee was divided into teams that focused on inclusive excellence, the undergraduate experience, professional masters degree offerings, and research. All the committee's work was shared online via SharePoint with all interested faculty. Additionally, undergraduate and graduate students provided input to the process through a survey, lunch meetings and participation in committee meetings. We are grateful to Amelia Coomber and Daniel Farrell for their contributions to this plan. Karla Raines, Principal at Corona Insights, was our strategic planning consultant.

Appendix B. 2017 Amplify Advisory Committee

The Amplify Advisory Committee will advise the School on Strategic Plan Implementation.

- Alan Cullop - CIO, DaVita Healthcare Partners
- Albert Kendrick – CIO, FirstBank
- Cheryl Bisque - CTO of Consumer Electronics, Amazon
- Craig Fletcher - Senior Manager, VM Ware
- Dale Drew, CSO, Level 3 Communications
- David Anderson – SVP, CIO, CH2M Hill
- Dawn Beyer – Fellow, Lockheed Martin
- Ingrid Alonghi – Co-founder, QuickLeft
- Jack Waters – CTO, President of Network Solutions, Zayo Group
- Jason Carolan – CTO, ViaWest
- Jay Jesse – President, Founder, Intelligent Software Solutions (ISS)
- Jim Franklin – Founder, SendGrid
- Joel Moxley – Founder, Moxley Holdings
- John Swieringa – EVP of Operations, DISH Network
- Julian Farrior – CEO, Founder, Backflip Studios
- Kishore Nayak – Former CIO, Gates Corporation
- Mark Hopkins – Founder, Crescendo Capital Partners
- Mark Turnage – CEO, OWL Cybersecurity
- Rob Meilen – Former CIO, Hunter Douglas
- Sally Hatcher, Founder, MBio Diagnostics
- Scott Brave - CTO, FullContact
- Steve Halstedt – Managing Director, Centennial Ventures
- Vincent Melvin – CIO, Arrow Electronics

Appendix C. 5-Year Financial Plan

In this section of the plan we present:

- FY '17 - FY'22 Pro Forma projections for Nominal and Strategic Growth
- FY '13 – FY '17 Financial performance data
- Initial space estimates for Nominal and Strategic Growth
- FY '17 – FY '22 initial scholarship fund estimates

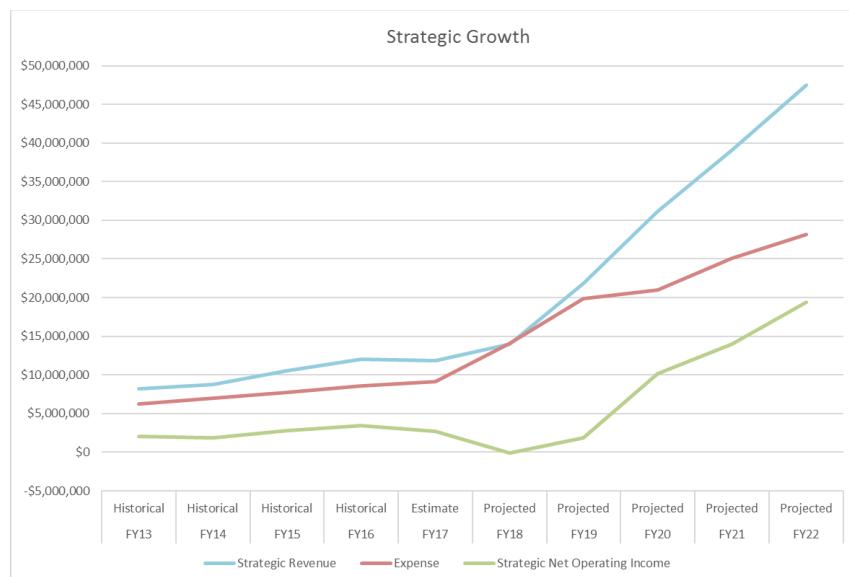
Ritchie School of Engineering and Computer Science
Strategic Plan

	NOMINAL GROWTH	FY18 Projected	FY19 Projected	FY20 Projected	FY21 Projected	FY22 Projected
Revenue						
Undergraduate	\$637,480	\$1,322,771	\$2,055,873	\$2,852,723	\$3,681,447	
Graduate	-\$19,156	\$4,996	\$17,072	\$29,148	\$53,300	
PMD Program	\$1,516,800	\$4,150,976	\$5,359,360	\$6,067,200	\$6,775,040	
Revenue Change from FY17 Estimated	\$2,135,124	\$5,478,743	\$7,432,305	\$8,949,071	\$10,509,787	
FY17 Estimated	\$11,837,208	\$11,837,208	\$11,837,208	\$11,837,208	\$11,837,208	
Projected Revenue	\$13,972,332	\$17,315,951	\$19,269,513	\$20,786,279	\$22,346,995	
Expense						
Permanent Faculty Additions	\$396,675	\$751,425	\$1,106,175	\$1,460,925	\$1,951,125	
Visiting Faculty	\$96,750	\$193,113	\$470,463	\$470,463	\$470,463	
Staff	\$92,880	\$157,380	\$208,980	\$260,580	\$312,180	
Other Labor	\$94,073	\$172,010	\$329,204	\$369,884	\$430,904	
Startup Expenses	\$1,000,000	\$1,000,000	\$1,000,000	\$1,000,000	\$1,500,000	
Materials & Operating	\$683,500	\$1,010,000	\$977,000	\$934,000	\$838,000	
Expense Change from FY17 Estimated	\$2,363,878	\$3,283,928	\$4,091,822	\$4,495,852	\$5,502,672	
FY17 Estimated	\$9,101,459	\$9,101,459	\$9,101,459	\$9,101,459	\$9,101,459	
Projected Expense	\$11,465,337	\$12,385,387	\$13,193,281	\$13,597,311	\$14,604,131	
Projected Net	\$2,506,995	\$4,930,564	\$6,076,232	\$7,188,968	\$7,742,864	
	STRATEGIC GROWTH	FY18 Projected	FY19 Projected	FY20 Projected	FY21 Projected	FY22 Projected
Revenue						
Undergraduate	\$637,480	\$1,912,440	\$4,127,683	\$7,729,445	\$13,450,828	
Graduate	-\$19,156	\$242,840	\$462,564	\$730,594	\$984,196	
PMD Program	\$1,516,800	\$7,791,296	\$14,763,520	\$18,757,760	\$21,235,200	
Revenue Change from FY17 Estimate	\$2,135,124	\$9,946,576	\$19,353,767	\$27,217,799	\$35,670,224	
FY17 Estimated	\$11,837,208	\$11,837,208	\$11,837,208	\$11,837,208	\$11,837,208	
Projected Revenue	\$13,972,332	\$21,783,784	\$31,190,975	\$39,055,007	\$47,507,432	
Expense						
Permanent Faculty Additions	\$464,400	\$1,470,600	\$2,660,625	\$4,376,325	\$6,898,275	
Visiting Faculty	\$696,600	\$715,563	\$1,441,138	\$1,999,113	\$2,276,463	
Staff	\$312,180	\$376,680	\$428,280	\$479,880	\$531,480	
Other Labor	\$148,061	\$424,185	\$955,898	\$1,453,564	\$1,935,288	
Startup Expenses	\$2,000,000	\$5,000,000	\$3,000,000	\$4,500,000	\$4,500,000	
Materials & Operating	\$1,329,840	\$2,811,840	\$3,428,340	\$3,138,840	\$2,904,840	
Expense Change from FY17 Estimate	\$4,951,081	\$10,798,868	\$11,914,281	\$15,947,722	\$19,046,346	
FY17 Estimate	\$9,101,459	\$9,101,459	\$9,101,459	\$9,101,459	\$9,101,459	
Projected Expense	\$14,052,540	\$19,900,327	\$21,015,740	\$25,049,181	\$28,147,805	
Net	-\$80,208	\$1,883,457	\$10,175,235	\$14,005,826	\$19,359,627	

Ritchie School of Engineering and Computer Science
5 Year Financial Analysis

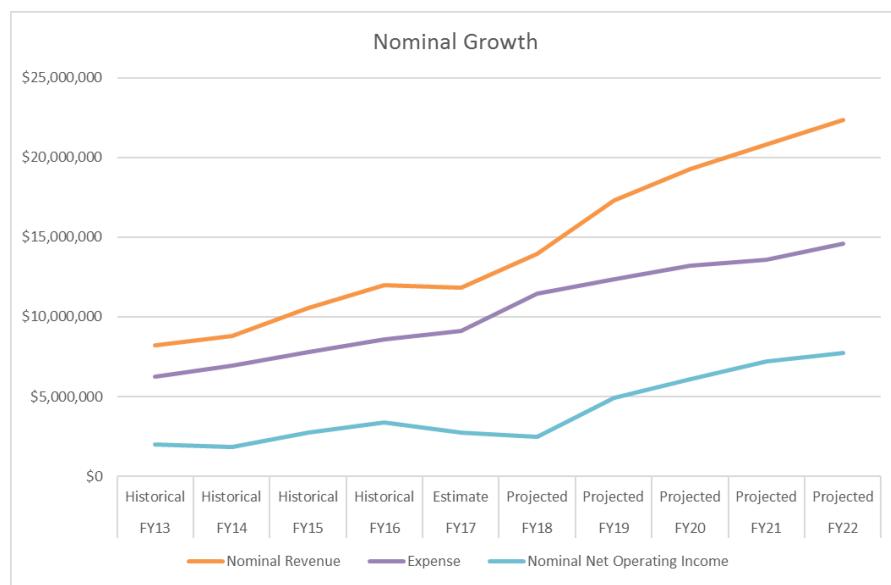
Revenue	FY13 Actual	FY14 Actual	FY15 Actual	FY16 Actual	FY17 Estimated
Tuition					
Undergraduate	\$ 4,788,725	\$ 5,440,037	\$ 6,786,513	\$ 8,252,871	\$ 8,854,288
Graduate	3,104,092	2,956,067	3,034,418	2,956,710	2,346,367
Summer	103,228	137,455	211,580	252,593	128,830
Tech Fees	21,872	23,168	26,775	29,116	29,563
Gifts	69,216	167,327	145,213	213,414	167,160
Sales	157,090	60,969	335,494	284,863	311,000
Total Revenue	\$ 8,244,223	\$ 8,785,023	\$ 10,539,993	\$ 11,989,567	\$ 11,837,208
Expenses					
Compensation	\$ 5,757,608	\$ 6,148,663	\$ 6,838,696	\$ 7,934,101	\$ 8,265,481
Materials & Operating	480,525	813,587	930,236	660,115	835,978
Total Expenses	\$ 6,238,133	\$ 6,962,250	\$ 7,768,932	\$ 8,594,216	\$ 9,101,459
Net	\$ 2,006,090	\$ 1,822,773	\$ 2,771,061	\$ 3,395,351	\$ 2,735,749

A side-by-side comparison of the two growth options illustrates the difference in year-over-year growth rate for revenue and net over the five year period. The charts also illustrate the continued increase in revenue over expense under Strategic Growth beyond the five-year planning horizon.



Projected Revenue, Expense and Net – Strategic Growth

In contrast to the Strategic Growth, the Nominal model illustrates fairly flat growth in revenue and net beyond the five-year time period.



Projected Revenue, Expense and Net – Nominal Growth

Estimates for the cumulative increase in revenue and net show a 64% increase in revenue over five years and a corresponding 59% increase in net for Strategic Growth compared to Nominal. The increase in net revenue is less than the increase in total revenue due to the larger investment required in faculty for the growing undergraduate and PMD programs, as well as additional faculty for the research enterprise. The larger faculty does result in increased research expenditures within the 5-year, and most especially within the longer 10-year projection period as illustrated in this Plan.

		FY17-FY22
Nominal Growth		Cumulative Change
Revenue		\$93,691,070
Net		\$28,445,623
Strategic Growth		
Revenue		\$153,509,530
Net		\$45,343,937
% Increase Strategic over Nominal		
Revenue		64%
Net		59%

*RSECS Strategic Plan
Space Needs Projection
Nominal Growth Assumption*

Headcount	FY18	FY19	FY20	FY21	FY22
Faculty					
New TT Research Faculty hires	2	2	2	2	3
TT offices needed	2	2	2	2	3
TT labs needed (assume 50% need traditional lab)	1	1	1	1	2
New Teaching Faculty hires -offices needed	2	1	1	1	1
Visiting Faculty					
UG/IE Visiting Faculty - 2 std offices; 3 small offices	0	-	-	-	-
PMD Visiting Faculty hires	2	1	3		
PMD offices needed (2/office)	1	1	1	4	1
PMD Adjunct offices (assume 1 office per degree)	1	-	-	-	-
Staff					
2 new hires PMD Administration (2 offices)	2	0	0	0	0
Diversity for .5 Fac Dir & 1 Admin Asst (one large office)	1	0	0	0	0
3 new hires dept admins (one std office each)	0	0	1	1	1
1 new IT support (assume he will share existing office)			0	0	0
New GTAs	2	2	2	2	3
Add'l GRA headcount	8	4	-	2	4
GRA offices (30% office in their respective labs)	3	7	8	12	19
On-campus	1	-	-	-	-
Total Trad Grads	6	9	10	14	22
PMD grad students (Cummulative)	80	120	160	180	200
# of degrees (1 600 sq ft study space/degree)	2				
Sq Ft Needed					
Faculty					
TT Research					
office @ 150	300	300	300	300	450
lab	1,500	1,500	1,500	1,500	3,000
Teaching -office	300	150	150	150	150
PMD Visiting - office	150	150	150	600	150
PMD Adjunct offices	150	-	-	-	-
UG/IE Visiting - 5 offices	-	-	-	-	-
2 new hires PMD Administration (2 offices)	300	-	-	-	-
Diversity for .5 Fac Dir & 1 Admin Asst (one large office)	400	-	-	-	-
Staff					
3 dept admins	-		120	120	120
GTA/GRA/Other Grads (15 desks/room)	0	600	600	600	600
PMD grads (assume 1 study room per degree)	1,200				
Additional Sq Ft Needed in each Year	4,300	2,700	2,820	3,270	4,470
Cummulative Sq ft needed	4,300	7,000	9,820	13,090	17,560

Assumptions
For a ground up building, current market, similar to Galvanize or WeWork runs \$175 to \$190 / sq ft with \$0 land cost

\$40-50 / sq ft Interior / Tenant Finish
DU typically apparently assumes a \$20 per square foot premium for its approach to tech, furniture and infrastructure, with \$0 land cost

RSECS Strategic Plan

Space Needs Projection Strategic Initiative Assumption

	<u>FY18</u>	<u>FY19</u>	<u>FY20</u>	<u>FY21</u>	<u>FY22</u>
Headcount					
Faculty					
New TT Research Faculty hires	0	5	7	11	17
TT offices needed	0	5	7	11	17
TT labs needed (assume 50% need traditional lab)	0	3	3	5	9
New Teaching Faculty hires -offices needed	0	4	3	4	7
Visiting Faculty					
UG/IE Visiting Faculty - 2 std offices; 3 small offices	5	-	-	-	-
PMD Visiting Faculty hires	2	6	10	7	3
PMD offices needed (2/office)	1	3	5	4	1
PMD Adjunct Offices (assume 1 office per degree)	2	3	2	-	-
Staff					
2 new hires PMD Administration (2 offices)	2	0	0	0	0
Diversity for .5 Fac Dir & 1 Admin Asst (one large office)	1.5	0	0	0	0
3 new hires dept admins (one std office each)	0	0	1	1	1
1 new IT support (assume he will share existing office)					
New GTAs	9	16	22	19	13
Add'l GRA headcount	4	10	12	17	27
GRA offices (30% office in their respective labs)	3	7	8	12	19
On-campus	1	4	1	2	3
Total Trad Grads	13	27	31	33	35
PMD grad students Cummulative)	80	300	490	560	630
# of degrees (1 600 sq ft study space/degree)	2	3	2		
Sq Ft Needed					
Faculty					
TT Research					
office @ 150	-	750	1,050	1,650	2,550
lab	-	4,500	4,500	7,500	13,500
Teaching -office	-	600	450	600	1,050
PMD Visiting - office	150	450	750	600	150
PMD Adjunct offices	300	450	300	-	-
UG/I/E Visiting - 5 offices	660	0	0	0	0
2 new hires PMD Administration (2 offices)	300				
Diversity for .5 Fac Dir & 1 Admin Asst (one large office)	400				
Staff					
3 dept admins	-		120	120	120
GTA/GRA/Other Grads (15 desks/room)	600	1200	1200	1200	1200
PMD grads (assume 1 study room per degree)	1,200	1,800	1,200	-	-
Additional Sq Ft Needed in each Year	3,610	9,750	9,570	11,670	18,570
Cummulative Sq ft needed	3,610	13,360	22,930	34,600	53,170
Cost per Sq Ft	\$260				\$13,824,200

Assumptions

For a ground up building, current market, like Galvanize or WeWork runs \$175 to \$190 / sq ft with \$0 land cost

\$40-50 / sq ft Interior / Tenant Finish

DU typically apparently assumes a \$20 per square foot premium for its approach to tech, furniture and infrastructure, with \$0 land cost

Total of \$235 to \$260 range

RSECS Strategic Plan
Undergraduate Enrollment
Strategic Initiative Assumption

Scholarship Endowment Need Calculation

Scholarship Expense	Fall 2017	Fall 2018	Fall 2019	Fall 2020	Fall 2021
Annual - New	\$84,000	\$497,000	\$903,000	\$1,512,000	\$3,696,000
Annual - Continuing		\$84,000	\$497,000	\$903,000	\$1,512,000
			\$84,000	\$497,000	\$903,000
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	\$84,000	\$581,000	\$1,484,000	\$2,996,000	\$6,608,000

Note: Scholarship need calculated at \$7,000 for each of 4 years for each additional female/minority student
A further assumption has been made that 1/3 of this population will be members of both categories

Appendix D. Undergraduate Student Survey Findings

Note - This report was created by Institutional Advancement and submitted to RSECS in early December 2016.

RSECS Undergraduate Excellence Survey and Clearinghouse Results

Section I. Engineering Undergraduate Excellence Survey: Open-Ended Item Analysis

The responses to the two survey items were independently reviewed and coded. The separate analyses were then reconciled. Comments were assigned all applicable codes from the coding scheme, and no codes are mutually exclusive.

Q1: Why did you decide to become an engineering or computer science major?

The decision to major in engineering or computer science seemed to be well-formed. The most prominent theme in response to this item was having an interest in EN or CS before college. Overall, 34% of respondents noted this pre-college discipline-specific interest. A quarter of respondents suggested deep and long-term interest in EN or CS, and a quarter suggested their decision was influenced by the challenging and intellectually stimulating nature of the discipline. Perceived aptitude in science, technology and math was mentioned by about 23% of respondents as a reason for deciding to major in EN or CS. Previous exposure to the field, the desire to build/create and the appeal of rapid innovation/progress were also each mentioned in about 15-20% of responses. Several students (11% of respondents) cited a specific interest in game development as an influential factor. Family ties to the field and the potential to impact/benefit society were mentioned by 13% and 9% of respondents, respectively. Earning and career potential was the second most common theme, occurring in 30% of responses. Nine (16%) of the respondents listed earning or career potential as their only motivation.

Of the 56 respondents, 44 (79%) listed Engineering as their intended college on their application. This is somewhat consistent with the actual trend over the last six years, where the percent of engineering majors who specified engineering on their application is in the low 80s, on average. Of the 12 individuals who did not list engineering on their applications, seven (58%) listed earnings and career opportunity as their primary motivations. Of the same 12 individuals, three listed a pre-college interest in engineering, and of the nine individuals who neither listed engineering on the application nor expressed a previous interest in EN/CS, seven (78%) cited potential earning and career potential as primary influences.

Overall, the decision to major in EN or CS is associated with clear reasons which are directly related to respondent beliefs about discipline fit, ambitions or the potential benefits of an EN or CS degree. There does seem to be some distinction between individuals who pursue engineering because of general interest and intrigue and those who predominately cite potential career and earnings benefits. Of the respondents who did not have previous interest in the discipline or a pre-college intent to attend the engineering school, a disproportionate amount report earnings and career prospects as a motivation.

Q2: Why did you decide to attend the University of Denver?

The decision to attend DU somewhat contrasted the decision to major in engineering in that it seemed less definite. Whereas respondents cited distinct and decided reasons for wanting to pursue EN or CS, their reasons for choosing DU seemed, on average, to have weaker intrinsic relationships. For example, reasons for pursuing EN or CS were related to merits of EN or CS, such as challenge, usefulness, interest, the potential for earnings, etc., while reasons for choosing DU were (in some instances) less directly merits of DU but instead desirable peripheral attributes such as cost, setting or distance from family. This was certainly not the case in every response, but it did seem to be an underlying theme.

The most frequently cited reason to attend DU was the setting, which was mentioned by 52% of respondents. These answers primarily concentrated on DU's proximity to the mountains and highlighted opportunities for recreation, although some students indicated that the proximity to the city of Denver was desirable. The second most common responses, occurring in 48% of records, related to non-EN/CS attributes of DU. These attributes varied, but included things like size of the school, opportunities to study abroad, the LEP program and overall institutional reputation. Financial aid packages were mentioned by 38% of respondents. 20% of students listed liberal arts attributes as reasons to attend DU. These attributes included small class sizes, close relationships with professors and ability to take humanities and business coursework outside of the major. 14% of respondents indicated that DU was their best option out of all of the schools they had applied to. Proximity to family/friends was mentioned in 9% of responses. 23% of respondents indicated that some aspect of the engineering program, whether it be curriculum, faculty or the availability of a certain program, influenced their decision to attend DU. The appeal of the new engineering facility was mentioned by 18% of respondents. Overall, 34% of respondents said their decision to attend DU was based on either an element of the engineering program or the new engineering facility.

The results of the survey, overall, suggest a variety of reasons for becoming and EN or CS major and attending DU. Generally, the responses indicate more certainty about what the student wants to major in and less certainty about which institution they want to attend. The majority of students seemed to choose DU because of offered financial aid, desire to live in Colorado or attributes of the institution not related to RSECS. Approximately a third of respondents, however, noted that some aspect of RSECS influenced their decision to attend DU.

There appear to be two distinct points at which undergraduate students are competed for by the school of engineering and computer science (and by the university as a whole). In the first phase, students with an explicit interest in EN or CS who apply and are admitted to DU are competed for against the other institutions to which they've applied. This survey has now provided some additional insights regarding the factors influencing the choice to attend DU. The second phase of competition for students occurs when matriculated students who had not expressed an interest in engineering or computer science during the application phase are competed for between the undergraduate units within DU. Currently about 20% of UG RSECS enrollments are comprised of students who did not designate engineering on their applications. This survey has also provided insight regarding the considerations made during the major selection process for this group. The final section of this analysis will now examine the alternative paths of potential UG engineering and computer science students in order to provide a more empirical description of competing institutions.

Section II. Non-Matriculated Student Paths

Over the past six fall first-time first-year admissions cycles (2011-2016) there have been 5,677 accepted undergraduate applications specifying engineering as the intended college. Of those applicants, 674 matriculated for an 11.9% yield. (Notably, about 95% of these matriculated students actually enroll as an engineering major in the first quarter.) Of the 674 matriculated students, 452 (67.1%) submitted a FAFSA. When completing a FAFSA, a student must select the institutions to which they would like their financial aid eligibility data sent. Each school receiving the FAFSA form also receives the list of schools to which the student had the FAFSA sent. Of the 452 FAFSA submissions from matriculated students who specified engineering on their DU application, 326 (72.1%) listed DU in the first or second choice slot. Of the 5,003 non-matriculated accepted applicants who specified engineering on their applications, 2,513 (50.2%) submitted a FAFSA to DU. It's likely that many more submitted a FAFSA, but through the Common Application DU is able to accept students who will not necessarily submit their federal financial aid applications to DU. Of the 2,513 non-matriculated FAFSAs 1,088 (43.2%) listed DU in the first or second slot. Note that FAFSA college choices are not necessarily a ranking, but the order in which institutions are listed does impact financial aid eligibility in some states, and research suggests that most applicants list schools in order of preference. Matriculated DU FAFSAs listed an average of 4.4 institutions while non-matriculated FAFSAs listed an average of 5.6 institutions.

The National Student Clearinghouse allows subsequent enrollment record searches at domestic institutions for prospective students. In order to examine the paths of the 5,003 non-matriculated accepted FTFY DU undergraduate engineering applicants over the last six years, enrollment records were requested. College enrollment records were obtained for 4,536 (90.7% of the applicants), suggesting that at minimum 90.6% enrolled at a college other than DU. The remaining 9.4% may have not enrolled at a domestic institution or may have enrolled at an institution that doesn't participate in the Clearinghouse. It's also possible that a match could not be obtained for other reasons, such as name changes or data inaccuracies.

The results of the data are summarized in terms of the first institution attended. It's possible that an individual will have enrollment records from a number of different schools but only the school associated with the initial enrollment record is considered here. The results indicate that 32.8% of students enrolled at a private institution. 23.1% enrolled at an institution in Colorado. There were 50 institutions that enrolled 20 or more applicants. 610 unique institutions were identified. The top five largest competitors were the University of Colorado Boulder, Colorado State University, Colorado School of Mines, California Polytechnic State University and University of Washington Seattle. The full aggregate table is available in the accompanying spreadsheet.

Appendix E. Faculty Size and Composition under Strategic Growth

RSECS Strategic Plan **Faculty FTE**

Faculty FTE	Historical				
	FY13	FY14	FY15	FY16	FY17
TT Research	26	26	26	26	27
Teaching	5.5	6.5	8.5	11.5	10.5
Total	31.5	32.5	34.5	37.5	37.5
UG Student/Faculty Ratio	9.3	10.9	13.8	14.5	15.3
Projected					
Faculty FTE	FY18	FY19	FY20	FY21	FY22
	29	31	33	35	38
Nominal	12	13	14	15	16
TT Research	41	44	47	50	54
Strategic	29	35	41	48	56
Teaching	11	11	15	23	39
Total	40	46	56	71	95

As detailed above, Strategic Growth projections estimate the faculty size will increase to 95 total from 37.5 today. Nominal Growth increases the size of the faculty to 54. Under the Strategic Growth Scenario, faculty will need to grow to serve larger undergraduate and graduate programs (including the Professional Masters) and the research enterprise. Three scenarios were explored to better understand the composition options of Tenure Track and Teaching faculty to serve the School's strategic aims. The table above is based on Scenario 3.

Faculty Growth Options

All scenarios

- Increase undergraduate enrollment to 25% of DU
- Maintain current student/faculty ratio (15:1)

Scenario 1

- Maintain the current tenure/teaching faculty ratio (70% / 30%)

Scenario 2

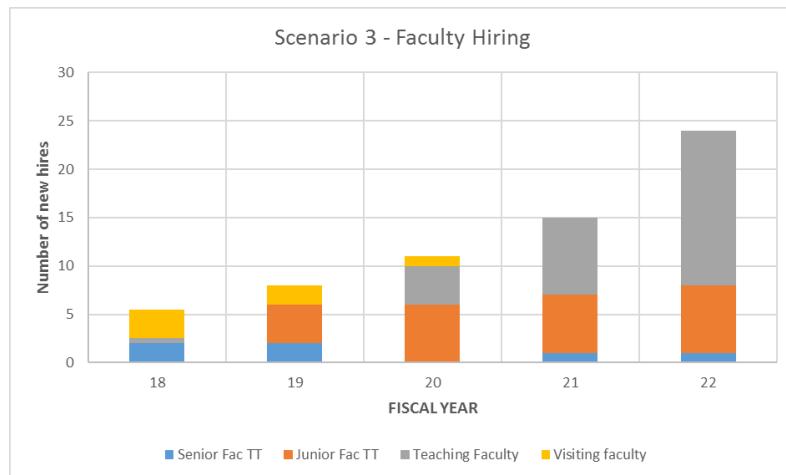
- 19 hires in 5 research areas are tenure-track; the rest of are teaching faculty

Scenario 3

- Tenure-track / teaching faculty is an average of Scenarios 1 and 2

As illustrated on the graph below, the composition of new faculty hires will vary each year as the School implements its strategy. The School will bring on a total of six (6) visiting faculty to provide expertise in

inclusive excellence and modernized pedagogy, with two who are highly expert in their fields and three total to support each of the departments. Key assumptions are outlined below.



Assumptions:

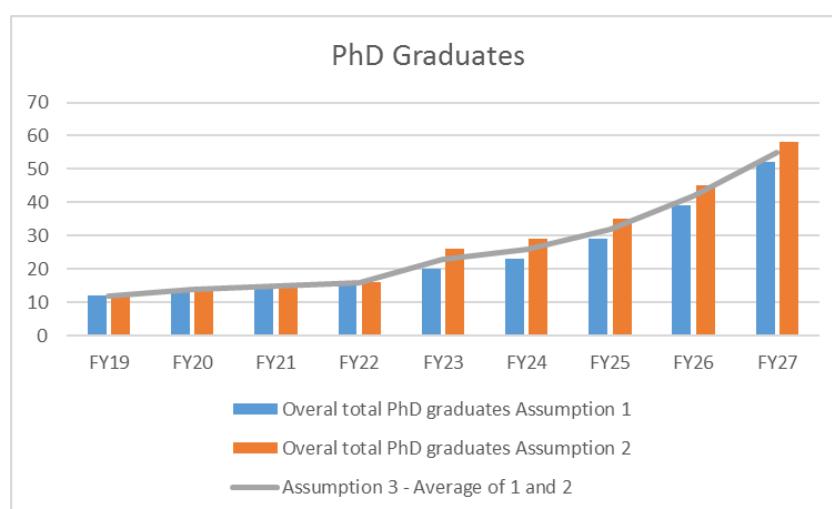
Cyber security and Data Science PMD programs are included in the Nominal assumption

Three (3) new PMD programs will be added in FY19, and two (2) more in FY20 (See Page 19)

Two (2) Senior and one (1) Junior faculty will be hired in FY18 to address Diversity/Ed Research initiatives;

Two (2) Junior in FY19, and one (1) Junior will be added in FY20

Growth in the number of PhD students was also explored for this Strategic Plan. The strategic focus on selected research areas will flow through with positive results for traditional graduate students. These students select their academic home based on faculty credentials, available labs and facilities, financial support and opportunities to launch successful careers.



Expected Growth in PhD Graduates FY'19 - FY '27

Appendix F. Ratings and Rankings Strategy

US News & World Report

US News and World Report rankings average three years of data. It does not rank undergraduate computer science programs.

Engineering

Undergraduate Overall Engineering

USNWR rankings for undergraduate engineering programs where the highest degree offered is as doctorate is based entirely on a survey of the deans of other ABET-accredited engineering programs.

- Current Rank: #183 out of 205 (tied with Catholic, North Dakota State, South Dakota State, Florida Atlantic University, Tuskegee University, Western Michigan, University of Missouri Kansas City, University of North Dakota, University of Tennessee Chattanooga)
 - 89th Percentile
- Goal for 2021: Achieve a ranking in the 85th Percentile

Undergraduate Engineering Specialties

USNWR ranks undergraduate programs where the highest degree offered is a doctorate in the following specialties available at RSECS: Computer Engineering, Electrical Engineering, Materials Science, Mechanical Engineering. These rankings are based 100% on a survey of department chairs.

- Current Rank: Rank not published
- Goal for 2021: Use learnings from campaign to improve overall engineering undergraduate ranking to focus on specialty specific rankings in the next five year period.

Graduate Overall Engineering

For overall graduate rankings, 40% of the ranking is based on reputation (survey of deans 25% and survey of employers 15%). For special rankings, 100% of the score is based on a survey of the deans.

- Current Rank: Rank not published (bottom 25%)
 - Peer: 1.8/5
 - Recruiter: 2.3/5
- Goal for 2021: Achieve a rank in the top 75% so we have a numerical ranking
 - Peer: 2.2/5
 - Recruiter: 2.8/5

Computer Science

Graduate Overall Computer Science

USNWR considers Computer Science under its Sciences Rankings. The overall rankings are based on surveys of deans and department chairs.

- Current Rank: Rank not published (average score lower than 2.0)
- Goal for 2021: Achieve a score of 2.0 in order to be numerically ranked

Graduate Computer Science Specialties

Computer Science specialties include Artificial Intelligence, Programming Language, Systems and Theory. Specialty rankings of doctoral science programs are based solely on nominations by department heads and directors of graduate studies at peer schools. These respondents ranked up to 10 programs in each area. Those with the most votes appear in the rankings. Thus, I do not recommend we consider specialty rankings for computer science. The lists are less than 20 schools long and include only the large, research universities you expect.

USN&WR Strategy Overview

In order to improve our rankings, and ultimately attract stronger applicants at both the undergraduate and graduate level, we will focus on a branding campaign that first builds name recognition for the Ritchie School of Engineering and Computer Science by highlighting RSECS faculty research, awards, grants, alumni success, student showcases.

- **Establish RSECS Positioning Statement**-To improve our reputation, we will first need to establish the RSECS brand positioning statement that infuses everything we do.
 - A strong positioning statement should:
 - Highlight points of differentiation with other engineering schools at liberal arts colleges
 - Complement the vision and mission statements
 - Be apparent to anyone who consumes our marketing collateral, visits our building, interacts with our faculty and students
 - Require sacrifices
 - A strong positioning statement should not:
 - Be generic, broad or grandiose
 - Highlight points of parity (ie. rigorous curriculum, small class size, small faculty to student ratio)
 - Attempt to be all things to all people
- **Introduce and reinforce our positioning through a variety of mediums**
 - Website
 - Monthly E-Newsletter to Engineering and Computer Science School Deans
 - Annual Report (Print and Digital)
 - Advertising (Traditional and Digital)

- Social Media (Facebook, Twitter, Instagram, Snapchat)
- Content Creation (Blogs, Videos, Photos, Infographics etc)

- **Host gathering of ECS deans and department chairs**
 - Tours of new building
 - Faculty research symposium
 - Notable alumni fireside chat
 - CO-based company networking opportunity
 - Student showcase
 - Timing:
 - i. Prioritize organizing before Ritchie Scholars graduate in 2018
 - ii. Coordinate with ski season (maybe include free passes, solicit discounts, provide transportation?)

QS Stars

QS World University Rankings is one of the two most respected rankings systems used by an international audience. However, this rankings system heavily favors research volume making it difficult for small universities to compete. To remedy this, QS introduced the QS Stars ratings systems.

The QS Starts rating system facilitates the evaluation of universities across a much broader range of criteria and with respect to established thresholds rather than the performance of others. **The objectives are to allow institutions to shine, irrespective of their size, shape and mission and to shine a light on excellence that may otherwise remain in the shade.**

Methodology

- Core Criteria (Teaching, Employability, Research, Internationalization)
- Learning Environment (Facilities OR Online/Distance)
- Specialist Criteria (Discipline Ranking and Accreditation)
- Advanced Criteria (Choose 2: Arts & Culture, Innovation, Social Responsibility, Inclusiveness)

Sample QS Stars Marketing



Strategy

RSECS recommends that the University of Denver undergo QS Ratings during the 2017-2018 year. The RSECS's Dean's office will work closely with the Provost and the office of Institutional Research to pursue this recommendation.

Game Development Program Rankings

Games Development Rankings Overview

Through our survey and informal conversations with undergraduates, it appears that many in the computer science department learned of the University of Denver because of its Games Development degree. Undergraduate degrees in Games Development are rare, and a point of differentiation for the DU and RSECS. Actively submitting data to rankings of Games Development programs will heighten RSECS's profile for students who are interested in Games Development.

Games Development Rankings Strategy

RSECS aims to be in the top 50% of the Games Development Rankings list the next time the lists are issued with our data included. Those lists include:

Princeton Review

Princeton Review ranks the top 50 Game Design programs and is public about its methodology. It's important that University of Denver submit the answers to this questionnaire and participate in this rankings program.

SuccessfulStudent.org

Successful Student recently listed their top 57 Video Game Colleges (up from 27 in 2015). While their methodology is unclear, DU and RSECS should pursue participation in this ratings system.

GameDesigning.org

GameDesigning.org listed the University of Denver as #49 in its top 50 Game Design Schools and Colleges, yet it doesn't appear that data specific to the Games Development program was actually submitted. If DU and RSECS actively submitted data specific to the Games Development program, it could achieve higher ranking on this list. DU and RSECS should submit data specific to the Games Development program to this list.

Appendix G. Inclusive Excellence Strategic Plan

Includes: Joint Inclusive Excellence / Undergraduate Excellence Strategy

RSECS Strategy and Rationale / Inclusive Excellence

Strategy statement

Our objective is to improve the culture and compositional diversity of RSECS at all program levels including students, faculty, and staff. Our most important and difficult challenge is creating a culturally inclusive culture: in the classroom, in faculty meetings, in research meetings, and outside of the classroom among our students and staff. This problem is exacerbated by the lack of role models, i.e. domestically diverse faculty and GTAs, lack of existing student body compositional diversity, as well as our lack of knowledge of inclusive cultural interactions. Our proposed approach is to implement culturally responsive interventions in each of the following areas: undergraduate and graduate student pedagogy; co-curricular activities; research; and K12 outreach. A quantitatively and qualitatively measurable inclusive program would give us a competitive recruiting and funding advantage.

One quantifiable indication of the lack of diversity in ECS is to look at current RSECS student body demographics (we note that this current compositional diversity was significantly skewed higher towards under-represented populations as a result of the Ritchie Scholar Program):

	Asian	Latino	African American	White	Non-resident	Male	Female
RSECS UG	6.2%	10.9%	1.1%	64%	10.9%	78.7%	21.3%
RSECS GRAD	5.6%	6.3%	2.1%	36.4%	45.4%	74.1%	25.9%

In addition, while not reported in the table above there are less than 1% native Americans at both the grad and undergraduate level, 1.4% (ugrad) and 4.4% (grad) who report as two or more races, and 2.1% (ugrad) and 2.1% (grad) unknown.

Our numbers are not too dissimilar to national numbers for computer science and computer engineering. In the table below we present numbers from the 2015 Taulbee Survey (which covers only computer science and computer engineering). Note, native American, native Hawaiian, and pacific islander representation is minuscule, and individuals who intersect female and underrepresented ethnicity, e.g. female and black, is almost non-existent. Recent previous year surveys show similar percentages.

	Asian	Hispanic	black	white	nonresident	male	female
CE BS	25.3%	9.4%	3.7%	50.5%	8.6%	88.4%	11.6%
CS BS	22.8%	7.0%	3.5%	55.0%	8.8%	84.3%	15.7%
CE MS	12.0%	2.3%	1.0%	17.0%	67.4%	76.1%	23.9%
CS MS	10.7%	1.6%	1.2%	17.2%	68.1%	75.1%	24.9%
CE Phd	4.7%	1.2%	0	26.7%	67.4%	85.2%	14.8%
CS PhD	6.4%	1.7%	1.0%	28.8%	60.7%	81.7%	18.3%

Perhaps more to the issue locally, regardless of the exact numbers, the climate of ECS could be improved to make our school more welcoming and supportive of all. Anecdotal evidence suggests this is not the case. A more scientific climate study is necessary to better identify areas of improvement opportunity.

We note that creating a more diverse environment will greatly improve outcomes within RSECS. In his 2014 Scientific American article, K. Gibbs makes the case that: a) diversity is a key to excellence as solving complex problems often results from diverse perspectives; b) lack of diversity represents loss of talent; c) enhancing diversity is key to long term economic growth and global competitiveness. It seems clear that ECS, which is missing the majority of the potential domestic population, clearly would benefit from increased diversity.

By creating a truly diverse and inclusive school, we would have competitive advantage in that we would be better able to provide students with the benefits accrued from being in a diverse/inclusive environment, better prepare students for a diverse workforce, better able to continue to attract diverse populations, increase faculty and research creativity, improve community perception of DU on a whole, be more attractive to employers who are specifically interested in recruiting diverse populations, and serve as a national role model. Simply put, RSECS would benefit in many ways.

Description

RSECS (and most Engineering and Computer Science nationally) are lagging in addressing IE. From a competitive perspective, the time is as soon as possible as many schools and funding programs are actively addressing IE, or the lack thereof, in ECS. By creating an inclusive and welcoming culture we will have a competitive advantage over other institutions that fail to act in this area, a problem that will only become exacerbated as the national demographics shift to more students of color. Further, graduating a diverse class would supply industry diversity needs.

Overall Model - The following four-part model guides our discourse below:

- C: COMPOSITION: refers to demographic make-up
- E: ENGAGEMENT: reflects personal, social, and professional commitment to institutional goals and activities; retention
- I: INCLUSION: comprises climate and interpersonal relations
- A: ACHIEVEMENT: reflects levels of attainment for underrepresented individual or group; opportunities

Overall Approach – We seek to integrate IE into as many RSECS processes and structures rather than create a separate IE center. Thus, our plan often overlaps with Undergraduate Excellence strategic plans as well as departmental activities.

TIMELINE:

Year 1:

C: Data collection (establish baseline to inform specific directions):

- a. Reference existing climate survey results for DU as needed
- b. Conduct an exemplar analysis and reference the exemplar and comparable universities:
Highlight what is working, what we could emulate, and best practices to adopt. Likely exemplars: Olin, Harvey, CMU grad, Dartmouth (50% female in grad engineering), UMBC, Cal-State System, ASU.

CEIA: Establish IE structures to oversee RSECS IE activities in a departmental/faculty integrated fashion. First year activities include: appoint faculty director (a member of the existing RSECS faculty), hire coordinator, obtain any needed physical space, create steering committee, and begin additional activities/details as described immediately below.

CEIA: Assemble RSECS IE Steering Committee and have them develop/approve VMG and two year goals. The committee will include at least one “champion” from each of the three ECS departments, one or both RSECS deans, at least one IE-related university administrator, one industry member, and possibly ECS focused ECS external organization members. The steering committee will establish specific qualitative and quantitative goals and process of ongoing evaluation of progress towards goals that address: a) climate change; b) compositional diversity (students, faculty, staff) recruiting and change; c) inclusive classroom practices; d) DU internal and external partnership building progress; e) outreach; and f) broadening participation scholarship.

CEIA: Work with “UE/IE cadre of 9 faculty” that includes the above mentioned three “champions” and IE faculty director. This cadre will serve as the driving force for RSECS curriculum and IE initiatives. The cadre will create/approve internal CFPs/grants for internal projects. These projects will have intertwined outcome goals of: measurable curriculum/IE impact aligned with UE goals; external funding

potential; and general equity impact. Example IE projects include inclusive curriculum pilots, mentorship pilots, and faculty IE knowledge building. Resources will be provided to incentivize faculty as well as cover any additional needed expenses.

CEI: Build strong partnership with National Center for Women & Information Technology (NCWIT) and Women in Engineering ProActive Network (WEPAN)

CEI: Initiate faculty/staff learning-community to better apprise ourselves of equity issues and initiatives in ECS.

CEI: Build advising/recruiting/mentoring pipelines with local K12 schools

CEI: Build advising/recruiting pipelines with tribal and community colleges.

E: Coordinate with VIP program to create ECS-VIP program with first on-campus camp in summer 2018.

CEIA: Hiring:

- (new position) IE/outreach coordinator. The coordinator will work with steering committee, chairs, dean's office, local schools, industry, and community partners to initiate, implement, and monitor all ICE Center activities as specified above.
- (new positions) 1 GSAs and 2-4 undergraduate assistants to support RSECS curriculum/research/efforts and first year of ECS-VIP program.
- (existing and/or new positions) Work with HCBUs and HSIs to recruit GTAs of color.
- (new position) Hire first one-year visiting faculty in "ECS Broadening Participation" - i.e. ECS education research specifically focused on broadening participation.
- (new positions) Hire one or more practitioners/professors-of-the-practice who support both internal curriculum and climate IE, recruiting, and outreach activities
- (new position) Hire one or more visiting researcher who broadens compositional diversity and works with one of the RSECS research groups.

Year 2:

C: Collect/track data for formative assessment to guide focus and modifications.

CEIA: Fund second round of pilots faculty/staff projects, begin work on sustainability including working with advancement and submitting external grant proposals.

CEIA: Hiring:

- (new position) Hire second one-year visiting faculty in "ECS Broadening Participation" - i.e. ECS education research specifically focused on broadening participation.
- (new position) Hire one or more visiting researcher who broadens compositional diversity and works with one of the RSECS research groups.

- Implement retention/support program for under-presented GTAs hired.
- (existing/new positions) Continue recruiting/hiring under-represented GTAs.
- (new positions) Continue recruiting/hiring GSA and undergraduate assistants to support IE efforts and ECS-VIP program as appropriate.

CEIA: IE Steering Committee convenes on ongoing basis to advise faculty IE director, chairs, deans, pertinent school committees, and consult with CDEAC (chancellor's diversity and equity advisory committee) and ODI and IRISE.

CEI: Continue advising/recruiting/mentoring pipeline building with local K12 schools, and initiate relationships with community and tribal colleges.

Years 3-5: Assess, Pivot, Accelerate

Target market

Our target “market” is not only all women and students of color, but all individuals including faculty and staff to enable a mindset shift towards true inclusivity.

Key competitors

While tempting to view competitors as traditional admission identified competing institutions, we propose it is wiser to identify key role models to learn from. (See timeline year 1). A detailed study, specifically what they did and outcome, should be done to better inform our plan. Exemplar institutions include Harvey Mudd, Olin, UMBC, WPI, and more generally, women’s colleges, HBCUs and HSIs. Examples of programs that support underrepresented populations include the Program for Women in Science and Engineering at Iowa State (<http://www.wise.iastate.edu/aboutpwse.html>) and the Engineering Mentoring for Internship Excellence program at Penn State (<http://psuengineeringdiversity.com/emix/>)

Cross-disciplinary opportunities

IE specific logical partnerships include: OTL, Interdisciplinary Research Incubator for the Study of (In)Equity (IRISE), the VIP Program, Center for Multicultural Excellence Pioneer Pathways Program (CME/P3), Colorado Women’s College (CWC), NCWIT, and WEPAN.

In addition, a logical extension of ICE to E-STEAM would be especially conducive to cross-disciplinary activities. For example, a recent NSF pre-proposal writing activity resulted in a gathering of faculty representatives from Art, Biology, Computer Science, Chemistry, Education, Mathematics, Mechanical Engineering, IRISE, and VIP (volunteers in partnership).

DU Impact 2025

Transformative Direction 4, Strategic Initiative 2 is:

"A Community of Diversity, Equity and Inclusive Excellence: a) create diversity, inclusive excellence plans for DU and units; b) create a diversity dashboard; c) expand search and improve procedures to promote diversity; and d) cultivate leaders committed to inclusivity."

In addition, Transformative Direction 2, Strategic Initiative 2 includes, "Develop unit plans for faculty diversity and inclusive pedagogy"

Thus, this RSECS IE SP is directly aligned with Impact 2025.

Industry partnerships / community relations

We have identified the following possible partners:

- Schools: All local school districts, but especially DPS, APS, and DSST
- Community: Chambers of Commerce: Black Chamber, Asian Chamber, Hispanic Chamber, and Women's Chamber
- Organizations: NCWIT, WEPAN, CABPES
- Industry: Arrow, Aspenware, Solidfire, Google, and many companies specifically interested in broadening industry compositional diversity in

Financial model

The financial needs are non-trivial. A strong effort would include funds for: a) pilot program development and implementation; b) required faculty/staff training; c) inclusive curriculum development; d) overall IE plan formative assessment; e) outreach projects; f) recruiting efforts; g) a willingness to consider "opportunity hires" when they occur; h) a significant increase in available scholarships to support both undergraduate and graduate ECS students from underrepresented groups with economic needs; and i) funding of the ICE center.

Appendix 1

Bullet Point Version (some redundancy, but also includes ideas not listed above)

In general, we need to work on all aspects (academic and social climate, student/faculty/staff compositional diversity, culturally responsive curriculum) of IE in RSECS at once, including:

- Outreach and K12 support / research:
 - Middle School and High School Camps - @ DU and @ schools
 - Faculty talks @ DPS/APS/DSST schools
 - Field trips from DPS/APS/DSST schools to DU
 - Create and get funding for “ECS-VIP” program, to include not only camps but also SAT preparation, DU students mentoring high school. Same as VIP but focuses on Computing and Engineering
 - HS students shadow DU students and/or faculty
 - Measurements ideas: number of visits, total schools “touched”, totals students “touched”, number students on campus, number talks at schools.... Attitudinal surveys (of students and faculty), retention numbers (participation in programs year to year), measurement of growth of programs.
 - Digital/internet clubs that tie together students from many schools
 - Participate/create/organize metro events/organizations. Possible orgs: female teams for first robotics; DPS first robotics teams; create local black girls code; create Latinas code;
 - Teacher Professional Development -> price according to school PD budget
 - RET (research experience for teachers)
 - REU SITE - specifically along ICE lines
 - Outreach to high school counselors
 - Outreach to families
 - Outreach CS/Engineering teachers
 -
- In partnership with Office of Admissions: active recruiting of women and SOC from high schools. Identify and utilize existing connections of promise: VIP, DSST, others? What are they doing now, how can we improve, how can we help.
- Create ICE Center (could put above two within and broaden participation to RSECS/NSM/EDP)
- Recruiting: better job of hosting prospective students: when identified as women or students of color should have prospective student meet with current student who is a female or student of color; should visit “good” classroom.
- Website needs to be more inclusive - but find balance between “real” and “aspirational”.

- Faculty/GTA education IE curriculum and classroom (new OTL associate director position).
Require IE curriculum training of all faculty? Require IE classroom support/training a category in annual faculty evaluations? Require IE question on teaching evaluations? Require education on new teaching techniques and examples. Example issues: shutting down grandstanding students; overcoming imposter syndrome; shutting down micro-aggressions; culturally responsive assignments/projects, managing “hot moments”.
- Working/reading group of faculty/students interested in IE issues. Documents to read (this list needs to be improved):
 - Book: Stuck in the Shallow End: Education, Race, and Computing. By Margolis, Estrella, Goode, Jellison Holme, and Nao
 - Movie: Code - debugging the gender gap (can get a copy from Erik Mitisek). Comcast sponsored this.
 - others?
- School wide events that speak to IE issues.
 - Talks: Speaker from NCWIT, WEPAN, etc.
 - Movies showing (ex: Code -debugging the gender camp)
- Recruit GTAs from women’s colleges, HBCUs and HSIs.
- Faculty compositional diversity -> recruiting needs to make compositional diversity (women and domestic minorities) a top priority.
- Make funds available for faculty exchanges (short visits to full semesters) with exemplar schools (UMBC, Harvey Mudd, others), locally - Metro State, Fort Lewis)
- Create RSECS Fund for IE projects, training, travel, and IE research
- Are there graduate student recruiter conferences? If so, we should be sending faculty and recruiters to such conferences to learn best practices. Get Associate Provost Wilcots involved on this. If does not exist, work with OGS to create such a consortium and/or conference.
- Financial: Work with advancement to create scholarships for women and students of color based on financial need. Work with existing programs such as Daniels Fund (creating at a really young age). Approach Boettcher Foundation? Could we partner with the Hispanic Chamber of Commerce, Black Chamber of Commerce, Women’s Chamber of Commerce, Denver Urban Scholars.
- Required mentorship program for first generation students. Cover study skills, practice sessions, tutoring, build network of fellow students to not only help with academics but also create

community. Students receiving DU financial aid/scholarship, the must participate in a two-year mentoring program. Program could also have a required mentoring of K12 student. Maybe require of ALL scholarship above a certain need threshold scholarship recipients. And open to all students? Key to be successful - near-peer mentoring experience but also meaningful buy-in in advising students in the departments.

- Encourage and support more student clubs to build community. Existing and health: DUCS, Women In Computing, Girls Who Code, VIP, First Robotics @ St. Mary's. Ones that could use help: ASME, IEEE, Society of Women Engineers, DUGOODS. One that could be created - inter-university org of women in computing.
- Alumni working with students.

What data needs to be gathered?

- Do a climate study for RSECS (students, faculty, staff)?
- RSECS demographics on a whole and breakdown by department
- National Demographics (Taulbee for CS, ASEE for Engineering???)

Other general ideas

- Look at other disciplines to see how they overcame it (bio medical, medicine, biology)
- Role model alumni working with our students
- Improve experiential and career services (internships, coops, hiring on campus, alumni for hiring network) and (interview skills, resume, professional eng/cs culture)
- Examples of successes to possibly emulate:
 - IA-State women engineers (Susanne knows about this)
 - Vanderbilt program (Debbie knows about this)

List of resources:

- Internal Programs/Organizations: P3, Roger Slaters Institute, CME, IRISE, CWC
- External Organizations: NCWIT, WEPAN, Black Girls Code, Technologochicas,
- Potential funding for efforts (research, programs/activities, scholarships): RSECS Dean's Office, NSF, NCWIT, WEPAN, IRISE, Philanthropy

Resource People:

- Lucy Saunders - CEO of NCWIT. JB has already reached out to her, and we just became an NCWIT Academic Alliance member. She is willing to serve as a resource.
- Tom Romero, Assistant Provost of IE research and curricular initiatives and head of IRISE. I am hoping our group comes up with specific plans in both IE research and curriculum, so it might be

good to hear from Tom. Also, we have a new IRISE postdoc coming, an anthropologist, who is working on studying attitudes/culture of African American Women in computing, so IRISE is relevant.

- Maria Salazar, Associate Professor in Morgridge. If we explicitly start talking about culturally responsive curriculum for Latina/os, she is an expert in K12 and could provide us some insights.
- Frank Tuitt, Sr. Advisor to the Chancellor and Provost on Diversity and Inclusion.
- Holly Okonkwo - IRISE Postdoc arriving end of September.
- Sheila Davis - UCollege program director and faculty - interested in working with us (and NSM) in writing grant proposals to create pipelines for women of color for grad school (Debbie says Vanderbilt has a program like this, Susanne says IA-State has a huge support network for women engineers)

UE/IE Joint Strategy

Guiding principles

A modernized RSECS undergraduate education is exemplified by the following.

1. All students participate in at least one (1) project-oriented, team-based, customer/product/service-driven, experiential, inclusive, and public-good oriented course each year:
 - a. Project-oriented
 - i. Build something that matters to someone (the customer); address/solve a real-world problem; and be relevant to students personally or culturally. The customer can be an outside person/entity or a faculty
 - ii. Builds skills
 - iii. Achieves defined learning objectives
 - iv. Achieves desired student outcomes for skills, knowledge, attitude and experience
 - b. Team-based
 - i. Students work in diverse teams of 3 or more (ideally)
 - c. Experiential
 - i. Students acquire a deeper knowledge through active exploration of real-world challenges and problems
 - d. Public Good Oriented
 - i. The project result is an artifact/service that helps mankind
 - ii. Diverse students are more engaged when project is culturally relevant
 - iii. Aligns with IMPACT 2025
 - e. Customer/product/service
 - i. The person/product/service whose needs must be satisfied by the project; the person/product/service defines the problem, sets the expectations and assesses the success of the solution
 - f. Inclusive
 - i. The project pedagogy will be informed by IE best practices. Instructors will work with the ICE Center during curriculum development, implementation, and assessment
 - g. *A note about flexibility*
 - i. The customer may be internal to RSECS or DU and the team may be a group of 2 students
2. All students engage in at least one (1) extra-curricular experience each year
 - a. Includes research, clubs, study abroad, service learning, etc.
 - b. Idea – adopt an annual student competition whereby groups of students (mix of years) work on teams; could be run with student leadership. Competition should have constraints and public-good focus.
3. All students have an internship or Co-Op before they graduate
 - a. Provides the real-world experiences students seek
 - b. Is a differentiator for DU in the (local) marketplace
 - c. Ties to the Grand Challenges program

- d. Will help drive cultural change within the school
4. All students have a Grand Challenges experience
 - a. RSECS will adopt a Grand Challenges-based program beginning in Fall 2017 with a scholars program cohort of 20; we will add a cohort of 20 each year to a full program of 80 scholars/
 - b. We will aim to serve a diverse group of under-represented students. Additional scholarship money will be raised to meet need (offset by merit scholarships)
 - c. The program could include a peer mentoring component; it could be designed to provide student leadership opportunities – students could run the program
 - d. That program will serve as a pilot model
 - e. The program will cascade each year as the incoming class of Fall 2017 advances in their education
 - f. This aligns with DU's grand challenges program outlined in Impact 2025
 5. All students are assessed annually against the five Ritchie School graduate characteristics (see below)

Characteristics of the Ritchie School graduate

Ritchie School graduates are defined by the following characteristics.

- Skills – they know how to work on diverse teams, communicate with different audiences, lead themselves and others and know how to get a job. The ICE-Center will be involved in assessing student ability to work and communicate in an inclusive manner.
- Knowledge - they graduate with a strong base of knowledge in their chosen field
- Attitude – Ritchie School graduates are ethical, passionate and have a sense of purpose. They demonstrate empathy for others. They have grit and determination
- Experience – they have a portfolio of educational, project and work experience that demonstrates their value-add to prospective employers

Inclusive excellence at the Ritchie School

Our objective is to improve the culture and compositional diversity of RSECS at all program levels including students, faculty, and staff. We note that creating a more diverse environment will greatly improve outcomes within RSECS. In his 2014 Scientific American article, K. Gibbs makes the case that: a) diversity is a key to excellence as solving complex problems often results from diverse perspectives; b) lack of diversity represents loss of talent; c) enhancing diversity is key to long term economic growth and global competitiveness. It seems clear that ECS, which is missing the majority of the potential domestic population, clearly would benefit from increased diversity.

Our IE plan, see attached, will result in an integrative center that infuses and supports inclusivity within all aspects of RSECS. Most pertinent to this section are the inclusive curriculum pilot projects, climate shaping, and outreach and recruiting efforts. Our efforts will be supported by having a more diverse student body, faculty and teaching assistants, and staff.

Students - By the end of the 21/22 Academic Year the Ritchie School will serve as an exemplar of inclusive excellence. Our curriculum and climate will be inclusive and welcoming, we will have ongoing efforts to attract and recruit diverse student populations, and compositionally our undergraduate

student body will be the most diverse ever. At least 50% of students will be female and at least 50% will be students of color. We also commit to growing the percentage of 1st generation students to at least 20% of all students. This new compositional diversity would be in stark contrast to our current composition – our fall 2016 freshman class of 152 full-time, first-year students is comprised of 21.3% women, 23.0% are students of color, and 16.4% are first generation college students. As found in our detailed IE plan, we will achieve these goals through a combination of having a welcoming climate with culturally relevant curriculum opportunities, K12 outreach and recruiting efforts, community and tribal colleges recruiting, and building a strong scholarship fund.

Faculty/Teaching Assistants – faculty and teaching assistants will be required to have inclusive pedagogy training and annual evaluations will include assessment of inclusive practices. Hiring a diverse faculty in engineering and computer science is especially problematic given the dearth of PhD graduates of color. In addition to working with the DU Director of Diversity Hiring, we will seek out and facilitate opportunity hires. We also plan to recruit graduate teaching assistants from HBCUs and HSIs as specified in our IE plan. This training, assessment, and recruiting efforts will be woven into RSECS and departmental administrative, hiring, and shared-governance processes.

Staff – New staff hiring will continue to use best practices to attract staff of color.

Grand Challenges Program – cascading growth plan and implementation by year

- Fall 2017
 - pilot year - 1st class of 20 scholars are freshman
- Fall 2018
 - 1st class of scholars are sophomores
 - 2nd class of scholars are freshman
 - begin to expand GC-based program (curricular and extra-curricular) for all freshman
- Fall 2019
 - 1st class of scholars are juniors
 - 2nd class of scholars are sophomores
 - 3rd class of scholars are freshman
 - continue to expand GC-based program for all freshman
 - begin to expand GC-based program for all sophomores
- Fall 2020
 - 1st class of scholars are seniors
 - 2nd class of scholars are juniors
 - 3rd class of scholars are sophomores
 - 4th class of scholars are freshman
 - continue to expand GC-based program for all freshman
 - continue to expand GC-based program for all sophomores
 - begin to expand GC-based program for all juniors
- Fall 2021
 - 2nd class of scholars are seniors
 - 3rd class of scholars are juniors
 - 4th class of scholars are sophomores
 - 5th class of scholars are freshman

- continue to expand GC-based program for all freshman
- continue to expand GC-based program for all sophomores
- continue to expand GC-based program for all juniors
- begin to expand GC-based program for all seniors

Educational Research / Inclusive Excellence – faculty and staffing needs

What capabilities do we need?

- Experience with successful curricular interventions
- Track record of bringing about cultural change
- Research-driven understanding of how change was achieved
- Ability to broaden participation in our fields

Necessary resources include support for: an annual visiting professor are working in broadening participation; two practitioners/professors-of-the-practice; a full-time IE and K12 outreach coordinator; support for a faculty director; and funding to supporting inclusive curriculum development, recruiting, and outreach efforts.

Appendix H. Undergraduate Excellence Strategic Plan

STRATEGY

The Ritchie School of Engineering and Computer Science will excel at preparing graduates to thrive in a dynamic and global environment. These students will be more diverse than any previous class; will have the theoretical foundation and technical skills required to be successful in an ever-changing workplace; will sharpen their ability to work in multi-disciplinary teams to solve complex problems; and will be prepared for advanced graduate work or a career in their field of choice.

By the end of the 21/22 Academic Year the Ritchie School will serve as an exemplar of inclusive excellence. Our curriculum and climate will be inclusive and welcoming, we will have ongoing efforts to attract and recruit diverse student populations, and compositionally our undergraduate student body will be the most diverse ever. At least 50% of students will be female and at least 50% will be students of color. We also commit to growing the percentage of 1st generation students to at least 20% of all students. This new compositional diversity would be in stark contrast to our current composition – our fall 2016 freshman class of 152 full-time, first-year students is comprised of 21.3% women, 23.0% are students of color, and 16.4% are first generation college students. As found in our detailed IE plan, we will achieve these goals through a combination of having a welcoming climate with culturally relevant curriculum opportunities, K12 outreach and recruiting efforts, community and tribal colleges recruiting, and building a strong scholarship fund.

Faculty and teaching assistants will be required to have inclusive pedagogy training and annual evaluations will include assessment of inclusive practices. Hiring a diverse faculty in engineering and computer science is especially problematic given the dearth of PhD graduates of color. In addition to working with the DU Director of Diversity Hiring, we will seek out and facilitate opportunity hires. We also plan to recruit graduate teaching assistants from HBCUs and HSIs as specified in our IE plan. This training, assessment, and recruiting efforts will be woven into RSECS and departmental administrative, hiring, and shared-governance processes.

New staff hiring will continue to use best practices to attract staff of color.

Characteristics of the Ritchie School graduate

Ritchie School graduates are characterized by the following.

- **Skills** – They can work on diverse teams, communicate with different audiences, think critically, and lead themselves and others. These lifelong learners can solve open-ended or ill-posed problems, where you are experimental with processes, and have IDEO design thinking ability (encompassing innovation and creation). They also have the know-how to obtain employment. The ICE-Center will be involved in assessing student ability to work and communicate in an inclusive manner.
- **Knowledge** - They graduate with a strong base of knowledge in their chosen field. They are equipped with the resources, ability and confidence to find and discern how to address issues, including those requiring digital literacy. They can find the resources to solve tomorrow's problems.

- Attitude – Ritchie School graduates are ethical, passionate and have a sense of purpose. They demonstrate empathy for others. They have grit and determination.
- Experience – They have a portfolio of educational, project and work experience that demonstrates their value-add to prospective employers.

DESCRIPTION

Because students have a vast number of options for an undergraduate education, the goal of the Ritchie School is to attract students who want a unique experience. The competitive attributes of the Ritchie School that should be highlighted in the undergraduate experience include:

- flexible course and concentration options;
- a small and intimate teaching environment;
- a high impact integrative curriculum;
- enriching outside-the-classroom experiences (i.e., undergraduate research, co-ops, internships, study abroad, etc.);
- a focus on ‘real world’ projects and occasions that include interdisciplinary, collaborative, and ‘messy’ customer related experiences; and
- an inclusive school culture serving a diverse student body that is reflective of our community and the globe.

The goal of the undergraduate experience is to not only graduate students who meet the requirements of an engineering or computer science degree, but to give these students value-added experiences that will make them more desirable and successful as employees. Denver’s setting in the Rocky Mountain region is one of innovative thought, independence, entrepreneurial spirit, and is considered one of the country’s major rising economies.

Today’s undergraduate expects hands-on and real-world learning experiences in the classroom and outside. Meeting the needs of the graduating class of 2025 necessitates a fully modernized curricular and extracurricular experience. The modern curriculum for undergraduates at the Ritchie School will embrace experiential learning methodologies, such as project-based learning, as well as other approaches that meet the needs of 21st century learners. Likewise, employers seek to hire graduates with real-world experience and look for demonstrated project and team experience.

As a small, private university (and one of the few in the Rocky Mountain region with both engineering and computer science programs), DU will amplify our student-focused undergraduate experience by providing each student with an education aligned with their passions and sense of purpose, both during their time at DU and when moving into the job market or advanced graduate education.

TARGET MARKET

The Ritchie School’s target market includes Denver, Colorado, national and international students pursuing an engineering and/or computer science undergraduate degree. More specifically our target market includes female students and students of color who are currently under-represented.

The dearth of students of color and females pursuing both engineering and computer science degrees is historic and well-documented. The Ritchie School faces this same challenge as illustrated by a demographic review of the incoming freshman class of 2016.

569 undergraduate students

152 full-time first-year students

21.3% are women

23.0% are People of Color

- <1.0% (2) American Indian or Alaska Native
- 6.2% (35) Asian
- 1.1% (6) Black or African American
- 10.9% (62) Hispanic or Latino
- 4.4% (25) Multiple (Two or More Races)
- <1.0% (1) Native Hawaiian or Other Pacific Islander

64.0% are White

10.9% are International

16.4% are first generation college students

Student-to-faculty ratio is 15 to 1

The Ritchie School is committed to creating an inclusive school culture and serving a diverse student body that is reflective of our community and the globe. For additional information about our inclusive excellence goals please see the Inclusive Excellence Plan.

The Undergraduate Experience at the Ritchie School

A Ritchie School undergraduate education includes a variety of curricular and extra-curricular activities, ranging from participating on multidisciplinary project teams and research teams, CO-OPs and internships with employers, study abroad opportunities and service learning experiences in the community.

We are committed to the following guiding principles.

Guiding Principle 1 - All students participate in at least one (1) project-oriented, team-based, customer/product/service-driven experiential, inclusive, and public-good oriented course each year

We define these elements of our program as follows.

Project-oriented – Students will build something that matters to someone (the customer). The customer can be an outside person/entity or faculty. The project will also be personally or culturally relevant. Projects will empower students to proclaim their personal interests and what is relevant to them. Additionally, projects will build skills, achieve defined learning objectives for the course, and achieve desired student outcomes for skills, knowledge, attitude and experience development.

Team-based - Students work in diverse teams of 3 or more students with complementary skillsets.

Experiential - Students acquire a deeper knowledge by solving real-world challenges and problems.

Public good oriented - The project result is an artifact/service that helps the community. The project result is an artifact/service that empowers broader communities through the learning laboratory of Denver and Colorado. Research shows that diverse students and underrepresented groups are more engaged when the project is culturally relevant. This also aligns with IMPACT 2025.

Customer/product/service - The person/product/service whose needs must be satisfied by the project. The person/product/service defines the problem, sets the expectations and assesses the success of the solution.

Inclusive – The project pedagogy will be informed by Inclusive Excellence best practices. Instructors will work with the ICE Center during curriculum development, implementation, and assessment

During the phase-in period, the customer may be internal to RSECS or DU and the team may be a group of 2 students. Annually we will compare this list of attributes against the NAE Grand Challenges Scholars program's five components and evaluate if our list needs to be revised.

Guiding Principle 2 - All students engage in at least one (1) extra-curricular experience each year

Extra-curricular experiences enrich learning inside and outside the classroom. Requiring undergraduates to participate in extracurricular activities outside of their regular classroom work encourage more well-rounded and motivated students. The Ritchie School is committed to providing a wide array of offerings including research, projects with Project X-ITE, study abroad, co-ops, internships, service learning, and clubs. Additionally, the School may adopt an annual student competition whereby groups of students (mix of years) work on teams, which could be run with student leadership. The competition would have appropriate constraints and a strong public-good focus.

Students can benefit from hands-on experience with research. These funded projects provide an opportunity to enrich the undergraduate education experience. We will attract and motivate undergraduate students to collaborate in larger, interdisciplinary or multidisciplinary research teams and ultimately offering uniquely qualified students for industry.

Many undergraduates are interested in entrepreneurship. The Ritchie School is joining the created the Kern Entrepreneurial Engineering Network ([KEEN](#)), part of the Kern Family Foundation's Entrepreneurial Engineering Program, which is a "collaborative partnership of colleges and universities dedicated to graduating engineers with an entrepreneurial mindset so they can create personal, economic, and societal value through a lifetime of meaningful work." The network trains faculty how to enhance curricula, and shares best practices across institutions. RSECS would be the logical school in Colorado to include in this network.

Another extracurricular focus would be to increase international relationships beyond traditional study abroad options. A 3+1+1 program with Glasgow University is being developed and is slated to start in Fall 2017. These kinds of programs where students study at DU for 3 years followed by 1 year at the undergraduate level at a university abroad result in a BS granted by DU. The following year, the student would study for an MS granted from the university abroad. The School would be interested in exploring more options like this, assuming that there is interest in the Glasgow program, and its implementation is successful.

Guiding Principle 3 - All students have at least one internship or Co-Op before they graduate

Co-Ops and internships provide the real-world experiences students seeks. Committing to this principle creates a strategic differentiator for DU in the local higher education. Marketplace. These experiences will also help drive cultural change within the school.

We will need to make our curriculum more flexible so that students have better options about where and when they can participate in a Co-Op. This would include offer courses throughout the year, including summer, and making room for students to take on Co-Op positions without feeling as if they are losing a full year of school.

Guiding Principle 4 - All students have a Grand Challenges experience

Beginning in Fall 2017, RSECS will adopt the [NAE Grand Challenges Scholars Program](#) with a cohort of 20; we will add a cohort of 20 each year to a full program of 80 scholars. This program incorporates five components: hands-on project or research experience, interdisciplinary curriculum, entrepreneurship, global dimension, and service learning. Details of the GCSP are to be worked out during the winter and spring quarters of 2017 with a projected date for the start of the first cohort being Fall 2017. One aspect of the program that should be considered is the establishment of a Living and Learning Community (LLC) as one of the options for the program. The development of the LLC also needs to be done during the winter and spring quarters. FSEMs could also be developed for the GCSP.

We will aim to serve a diverse group of under-represented students. Additional scholarship money will be raised to meet need (offset by merit scholarships). The program could include a peer mentoring component; it could be designed to provide student leadership opportunities – students could run the program. The NAE Grand Challenges scholars program will serve as a pilot model for the diffusion of a grand challenges experience for all students.

The Ritchie School will adopt a [Grand Challenges program](#) encompassing the NAE Grand Challenges, UN Sustainability Goals, and others such as the Social Work Grand Challenges. This aligns with DU's grand challenges program outlined in Impact 2025. The program will expand each year as the incoming class of Fall 2017 advances in their education. By Fall 2021 every freshman will have a Grand Challenge path to graduation.

Guiding Principle 5 - Faculty commit to a high level of engagement with students inside and outside the classroom

Faculty serve as important role models, mentors, and educators. As a small school, we will actively support a strong sense of community among students and with faculty and staff.

Guiding Principle 6 - All students are assessed annually against the Ritchie School graduate characteristics

It is important for students to receive regular feedback about how they are progressing in the development of the skills, knowledge, attitude and experience necessary for success in their careers and life.

Diversity and Inclusive Excellence in the Undergraduate Program

The Ritchie School is committed to creating an inclusive school culture and serving a diverse student body that is reflective of our community and the globe. We are launching a new initiative to imbed inclusive excellence into the school and tightly align it with our strategic focus on undergraduate excellence (see next page). For additional information about our inclusive excellence goals please see the Inclusive Excellence Plan.

When the Ritchie Scholarship was established for the 2014 freshman class there was an incidental increase in diversity of the class because of the increase in need based funding to students. Reestablishing this scholarship would help with diversity, but that there should be a focus on achievement and underrepresented groups.

The inclusive excellence section of the strategic plan addresses the K-12 pipeline and strategic relationships with higher education institutions that serve under-represented populations.

An Inclusive and Modern Undergraduate Program for 21st Century Learners

We are launching a faculty-driven, school-wide initiative to embrace inclusive excellence and modern teaching pedagogies throughout the school. Given our small size and recognition that culture change is paramount to achieving our goals of broadened participation in a modernized undergraduate curriculum, we are establishing a single team to achieve these interrelated strategic aims. The team will be responsible for implementing the inclusive excellence and undergraduate excellence strategic plans (see appendix) with strong connections to research through our new Global Challenges rubric.

The team will be comprised of 9 forward thinking faculty with the passion and sense of moral imperative to change the curriculum and who view everything through a lens of inclusive excellence. It will include research and teaching faculty; at least one faculty per department will be a research faculty who can inspire peers. There will be three faculty from each department.

The team will be led by Faculty Director(s) and supported by a Staff Coordinator. It will also include GTAs/GRAS/UTA who will be involved in curriculum development. This approach will facilitate mentoring and shared learning, and expose PhD student to new pedagogy implementation.

Recommendations for visiting faculty include:

- One (1) visiting professor in broadening participation / inclusion to fill our gaps in understanding, help us apply the pedagogies and do research
- One (1) visiting professor in modernized undergraduate education to fill our gaps in understanding, help us apply the pedagogies and do research
- Two (2) "Professors of the Practice" – practitioners or researchers who will work with the faculty in broadening participation and outreach to K-12 partners
- A Steering Committee
- An Industry Advisory Committee

The team's role is to:

- Implement the Inclusive Excellence and Undergraduate Experience strategic plans (attached)
- Create the diffusion models necessary to expand from pilots to school-wide adoption
- Oversee and implement all aspects of the work
- Be champions of change and serve as role models
- Lead by example and inspire other faculty members. Suggest new models and demonstrate their use
- Support diffusion and adoption across the school
- Write grant proposals and manage grants

We will support culture change with a variety of approaches including:

- Revising our hiring model to include this in our selection criteria
- Connecting to strategic research areas via our two Global Goals
- Establishing Learning Communities to support the “whole student experience” using the Grand Challenges Scholars as an example
- Funding for pilots, K-12 outreach and K-12 interventions
- Faculty release time, professional development, travel funds, annual evaluation and metrics, and compensation for faculty director(s)

Cross-Disciplinary Opportunities

This plan embraces cross-disciplinary opportunities within the school, across the campus, and with the Denver community. To highlight one of several examples described in more detail in below, the school is adopting the National Academy of Engineering’s Grand Challenges model and will be creating a Grand Challenges Scholar Program (GCSP) for a select group of engineering and computer science students. By participating in this program the Ritchie School will be part of a cohort of schools that are engaging engineering and computer science students in solving society’s biggest problems. The Ritchie School will join GSSW in adopting a grand challenges framework in its field, with others DU schools to possibly join this national movement. Establishing this program also creates a platform for pilot studies that could reach the entire Ritchie School population.

Distinction within DU Context

Undergraduate education at the Ritchie School has the opportunity to distinguish itself in a few notable ways within the University. First, as a school that houses four academic disciplines, we are recommending pedagogical changes in each discipline that embrace new models, and are interested in exploring possibilities of joint offerings across the disciplines. The school is also interested in prototyping new pedagogies and models, learning from them, replicating best practices, and sharing our learnings across the DU teaching community.

DU Impact 2025 Strategic Plan

Our strategic plan aligns with all four transformative directions of the University’s Impact 2025 Strategic Plan.

- *Student learning and leading in a diverse and global 21st century* – Curricular and extra-curricular programs reflect the relevant needs of today’s learner, such as students curating offerings in the Maker Space
- *Discovery and design in the age of collaboration* – Opportunities to work on research projects in areas such as robotics, smart cities and health, as well as exposure to real-world issues through Project X-ITE and the KEEN entrepreneurial program, among others
- *Engagement and empowerment in Denver and the Rocky Mountain West* – Grand Challenges scholars will have opportunities to work collaboratively to address big problems in our local community and across the globe through multi-year course-based projects in computer science, engineering grand challenges, and service learning projects

- *One DU* – The Ritchie School can play a role in advancing the University’s commitment to serve the public good as we embrace inclusive excellence, such as Ritchie students teaching coding to underserved youth in the community

Industry Partnerships / Community Relations

Industry partners play a key role in curricular and extracurricular offerings. In particular, the large-scale project-based computer science courses and internship and Co-Op programs rely on partnerships with companies. The Ritchie School’s offerings are expected to grow and the number and variety of industry partners will need to grow as well. Community partners will also play a vital role in the implementation of the grand challenges program and other community service projects.

NAE Grand Challenges

On March 23, 2015, the Interim Dean of the Ritchie School, Mike Keables, submitted a letter to the National Academy of Engineering (NAE) saying, “our faculty are devoted to producing the next generation of computer scientists and engineers equipped with the necessary skills to address societal needs such as those outlined in the NAE Grand Challenges for Engineering.”

A Grand Challenges Scholars Program (GCSP) will be established and developed for all students interested in the 5 components embraced by the program: hands-on project or research experience, interdisciplinary curriculum, entrepreneurship, global dimension, and service learning. This program would also touch on another major emphasis, Extracurricular Activities. Details of the GCSP are to be worked out during the winter and spring quarters of 2017 with a projected date for the start of the first cohort being Fall 2017. One aspect of the program that should be considered is the establishment of a Living and Learning Community (LLC) as one of the options for the program. The development of the LLC also needs to be done during the winter and spring quarters. FSEMs could also be developed for the GCSP.

Connecting Educational Programs with Faculty Research

The committee of Research Centers of Excellence highlighted the importance of clustering faculty with complementary and overlapping expertise to achieve increased scale, success, impact and funding. These funded projects provide an opportunity to enrich the undergraduate education experience. Furthermore, it is important to support the strategic investment of resources to create high quality research areas, laboratories and computational facilities. This will contribute to attracting and motivating undergraduate students to collaborate in larger, interdisciplinary or multidisciplinary research teams.

The Engineering departments and Computer Science have faculty with key complementary expertise that allow DU to propose larger projects, which span expertise and capabilities, offering unique high qualified students for industry.

Faculty Development

One way that DU currently stands out among local institutions is the cultural emphasis on smaller class sizes and professor-student relationships. Over the past few years, increases in enrollment have threatened the student-faculty ratio, making especially first and second year classes at DU look similar to

the much larger institutions in Colorado. Because of DU's history as a small, private institution, the ability to maintain smaller class sizes is a competitive advantage, and needs to be brought back into focus. This may include hiring more teaching faculty in order to increase the number of class sections taught each quarter.

Additional areas of priority for faculty development include focusing on faculty development in teaching, access to conferences, and an emphasis on educational research. Faculty should be encouraged to include more student feedback in the development of courses, either done through surveys or even a student based feedback committee. Finally, we suggest looking into staffing some larger lab-based classes (for example, introductory courses) with instructors to help develop and run the large number of labs.

Digital Literacy Development

The following definition of Digital Literacy resonated with the Undergraduate Excellence committee: the ability to use information and communication technologies to find, evaluate, create, and communicate information, requiring both cognitive and technical skills. In other words, the goal is to teach digital skills, and to teach students how to filter, use, and create new things using this information. In addition, students should have digital literacy integrated early on and continuously throughout their time at DU, in a similar way to writing-intensive courses.

There are several possible strategies that have been considered for Digital Literacy (DL) Development across DU. A separate committee explored many strategies and settled on a competency based framework developed by the European Commission on Digital Competence (DIGCOMP: A Framework for Developing and Understanding Digital Competence in Europe). In this report is a developed framework that was created with input from a large number of constituencies and includes the following set of competencies:

1. Information: identify, locate, retrieve, store, organize and analyze digital information, judging its relevance and purpose.
2. Communication: communicate in digital environments, share resources through online tools, link with others and collaborate through digital tools, interact with and participate in communities and networks, cross-cultural awareness.
3. Content-creation: Create and edit new content (from word processing to images and video); integrate and re-elaborate previous knowledge and content; produce creative expressions, media outputs and programming; deal with and apply intellectual property rights and licenses.
4. Safety: personal protection, data protection, digital identity protection, security measures, safe and sustainable use.
5. Problem-solving: identify digital needs and resources, make informed decisions as to which are the most appropriate digital tools according to the purpose or need, solve conceptual problems through digital means, creatively use technologies, solve technical problems, update one's own and others' competences.

In general, the committee felt that taking this approach towards digital literacy at DU would allow development something that was measurable. A single 10-week course could be developed to cover Information, Communication, Safety and basic Content-creation. In addition, majors should be required to meet Content-creation and Problem-solving competencies in a fashion that is specific to their majors.

This would be a University-wide requirement—each unit would need to demonstrate they meet these competencies with regards to their major.

Resources are needed to provide a position in support of digital literacy at DU (coordinating with all majors for #3 and #5, assessing their outcomes, and then redefining DL at DU as the digital world changes over time). In addition, they would possibly be in charge of developing the 10-week course in DL.

Success Measures

At the end of the 2021/2022 Academic Year we will have:

- Implemented a fully modernized engineering and computer science curriculum
- Provided every student with at least one experiential quarter activity before graduation including CO-OPs, internships, study abroad, service learning and student-led opportunities.
- Improved student learning outcomes as measured by:
 - o Students have acquired a deeper knowledge of all course material
 - o Increased diversity of the student body
 - o Increased retention of students
 - o Increased quality of students
 - o Increased quality of graduates
- Raised sufficient funds for the Ritchie scholars program for underrepresented students in CS and Engineering.
- Created a Grand Challenge path to graduation for every Fall 2021 incoming freshman.

Implementation Plan

1st Quarter 2017

- Define what a Grand Challenge school program experience will entail (see Engineeringchallenges.org/Grandchallengescholarprogram.org)
- Grand Challenges Program-Set up LLC Spring 2017

	AY 17/18	AY 18/19	AY 19/20	AY 20/21	AY 21/22
Offer a fully modernized curriculum	TBD	<p>Establish learning outcomes</p> <p>Student feedback</p> <ul style="list-style-type: none"> - Gather regularly to inform and improve offerings 	<p>Assess learning outcomes</p> <p>Student feedback</p> <ul style="list-style-type: none"> - Gather regularly to inform and improve offerings 	<p>Student feedback</p> <ul style="list-style-type: none"> - Gather regularly to inform and improve offerings 	<p>Student feedback</p> <ul style="list-style-type: none"> - Gather regularly to inform and improve offerings
Expand interdisciplinary learning opportunities inside and outside the classroom	<p>Grand Challenges program</p> <ul style="list-style-type: none"> - Set up LLC Spring 2017 - Implement Fall 2017 - Implement Grand Challenges Scholars Program for 10% of students Fall 2017 - Establish learning outcomes <p>KEEN program</p>	<p>Grand Challenges program</p> <ul style="list-style-type: none"> - Assess learning outcomes - Offer/Expand scholars program <p>KEEN</p> <ul style="list-style-type: none"> - Expand program involvement <p>BSE</p> <ul style="list-style-type: none"> - Oversee degree program 	<p>Grand Challenges program</p> <ul style="list-style-type: none"> - Grow program - Assess outcomes <p>KEEN</p> <ul style="list-style-type: none"> - Increase participation - Assess outcomes <p>BSE</p> <ul style="list-style-type: none"> - Increase class size - Assess learning outcomes <p>Student feedback</p>	<p>Grand Challenges program</p> <ul style="list-style-type: none"> - Manage program - Assess outcomes <p>KEEN</p> <ul style="list-style-type: none"> - Manage program - Assess outcomes <p>BSE</p> <ul style="list-style-type: none"> - Increase class size - Assess learning outcomes <p>Student feedback</p>	<p>Grand Challenges program</p> <ul style="list-style-type: none"> - Manage program - Assess outcomes <p>KEEN</p> <ul style="list-style-type: none"> - Manage program - Assess outcomes <p>BSE</p> <ul style="list-style-type: none"> - Manage program - Assess learning outcomes <p>Student feedback</p>

	AY 17/18	AY 18/19	AY 19/20	AY 20/21	AY 21/22
	<ul style="list-style-type: none"> - Implement Fall 2017 - Establish learning outcomes BSE degree - Launch Fall 2017 - Establish learning outcomes Student feedback - Gather regularly to inform and improve offerings 	<ul style="list-style-type: none"> - Assess learning outcomes for BSE Interdisciplinary at DU - Research more options for real interdisciplinary work between units at DU, not just within ECS Student feedback - Gather regularly to inform and improve offerings 	<ul style="list-style-type: none"> - Gather regularly to inform and improve offerings 	<ul style="list-style-type: none"> - Gather regularly to inform and improve offerings 	<ul style="list-style-type: none"> - Gather regularly to inform and improve offerings
Increase student involvement in extracurricular activities	Engr & CS <ul style="list-style-type: none"> - Establish a process to oversee these activities - Expand Co-Op Program. Secure necessary staffing and industry partnerships - Expand Internship Program. Secure necessary staffing and industry partnerships - Expand undergraduate research. Secure funding for 	Engr & CS <ul style="list-style-type: none"> - Refine Co-Op program - Refine Internship program - Offer study abroad opportunities - Offer Community Service Projects - Gather student feedback regularly to inform and improve offerings 	Engr & CS <ul style="list-style-type: none"> - Manage Co-Op program - Manage Internship program - Offer study abroad opportunities - Offer Community Service Projects - Gather student feedback regularly to inform and improve offerings 	Engr & CS <ul style="list-style-type: none"> - Manage Co-Op program - Manage Internship program - Offer study abroad opportunities - Offer Community Service Projects - Gather student feedback regularly to inform and improve offerings 	Engr & CS <ul style="list-style-type: none"> - Manage Co-Op program - Manage Internship program - Offer study abroad opportunities - Offer Community Service Projects - Gather student feedback regularly to inform and improve offerings

	AY 17/18	AY 18/19	AY 19/20	AY 20/21	AY 21/22
	<p>students and faculty</p> <ul style="list-style-type: none"> - Offer study abroad opportunities - Offer Community Service Projects - Gather student feedback regularly to inform and improve offerings <p>CS</p> <ul style="list-style-type: none"> - Inspire students to participate in activities and provide resources to support them 				
Support faculty development	<p>Train faculty winter/spring 2017 on modern learning pedagogies in partnership with OTL</p> <p>Train faculty in learning outcomes measurement as necessary in partnership with OTL</p> <p>Hire Teaching Faculty and student/TA support to cover</p>	<p>Train faculty on modern learning pedagogies in partnership with OTL</p> <p>Train faculty in learning outcomes measurement as necessary in partnership with OTL</p> <p>Assess Teaching Faculty and student/TA needs</p>	<p>Train faculty on modern learning pedagogies in partnership with OTL</p> <p>Train faculty in learning outcomes measurement as necessary in partnership with OTL</p> <p>Assess Teaching Faculty and student/TA needs</p>	<p>Train faculty on modern learning pedagogies in partnership with OTL</p> <p>Train faculty in learning outcomes measurement as necessary in partnership with OTL</p> <p>Assess Teaching Faculty and student/TA needs</p>	<p>Train faculty on modern learning pedagogies in partnership with OTL</p> <p>Train faculty in learning outcomes measurement as necessary in partnership with OTL</p> <p>Assess Teaching Faculty and student/TA needs</p>

	AY 17/18	AY 18/19	AY 19/20	AY 20/21	AY 21/22
	<p>increased course loads for Fall 2017</p> <p>Provide financial resources to inspire curricular innovation</p> <p>Partner with OTL to create opportunities for faculty to learn about each other's work across departments within RSECS and DU</p> <p>Utilize Activity Insight to find partnering opportunities</p>	<p>Provide financial resources to inspire curricular innovation</p> <p>Partner with OTL to create opportunities for faculty to learn about each other's work across departments within RSECS and DU</p> <p>Utilize Activity Insight to find partnering opportunities</p>	<p>Provide financial resources to inspire curricular innovation</p> <p>Partner with OTL to create opportunities for faculty to learn about each other's work across departments within RSECS and DU</p> <p>Utilize Activity Insight to find partnering opportunities</p>	<p>Provide financial resources to inspire curricular innovation</p> <p>Partner with OTL to create opportunities for faculty to learn about each other's work across departments within RSECS and DU</p> <p>Utilize Activity Insight to find partnering opportunities</p>	<p>Provide financial resources to inspire curricular innovation</p> <p>Partner with OTL to create opportunities for faculty to learn about each other's work across departments within RSECS and DU</p> <p>Utilize Activity Insight to find partnering opportunities</p>
Ensure accountability and success measurement	<p>Assign faculty leads to all objectives</p> <p>Develop protocol to assess performance against the strategic plan's success measures</p> <p>Measure success</p> <p>Identify areas of improvement</p> <p>Report to faculty</p>	<p>Assign faculty leads to all objectives</p> <p>Measure success</p> <p>Identify areas of improvement</p> <p>Report to faculty</p>	<p>Assign faculty leads to all objectives</p> <p>Measure success</p> <p>Identify areas of improvement</p> <p>Report to faculty</p>	<p>Assign faculty leads to all objectives</p> <p>Measure success</p> <p>Identify areas of improvement</p> <p>Report to faculty</p>	<p>Assign faculty leads to all objectives</p> <p>Measure success</p> <p>Identify areas of improvement</p> <p>Report to faculty</p>
Align with DU Impact 2025	Leverage resources for pilots, etc.	Leverage resources for pilots, etc.	Leverage resources for pilots, etc.	Leverage resources for pilots, etc.	Leverage resources for pilots, etc.

	AY 17/18	AY 18/19	AY 19/20	AY 20/21	AY 21/22
	Report out on efforts and results that advance with DU 2025 implementation	Report out on efforts and results that advance with DU 2025 implementation	Report out on efforts and results that advance with DU 2025 implementation	Report out on efforts and results that advance with DU 2025 implementation	Report out on efforts and results that advance with DU 2025 implementation

Appendix I. Professional Master's Degree Program Strategic Plan

Strategy Statement

By offering a comprehensive suite of Professional Masters Degrees, the Ritchie School of Engineering and Computer Science (RSECS) will defend its current position and drive incremental growth in its share of the masters degree market in the metro areas of Denver, Boulder, Colorado Springs and Fort Collins.

Strength of Colorado's STEM Economy

In October, Colorado's unemployment rate fell to 3.5% of 2016, while the overall US unemployment rate is 4.9%. According to the Colorado Department of Labor and Employment, metro Denver (which accounts for 55% of Colorado's employment) has shown growth rates of 3-4% over the past year, and has been at top-five state for job growth since 2012.

Recently, the Milken Institute issued a report ranking Colorado #2 on its State Technology and Science Index, a measure of the state's innovation pipeline. In 2015, the Milken Institute listed Denver, Boulder and Fort Collins on its list of Top 25 Best-Performing Large Cities index. The index shows where employment is stable and expanding, wages and salaries are increasing, and economies and businesses are thriving. According to the US Chamber of Commerce 2016 Innovation that Matters Report, Denver is ranked 3rd in preparedness for the digital economy, after Boston and the Bay Area. Although Denver has fewer startups than other cities on the list, its high ranking on this list is due to "stronger ties between the startups and institutions in the community."

Talent Shortage in Computer Science and Engineering

There is a growing talent shortage in computer science and engineering-related careers in the United States and globally. In launching its Tech Hire Initiative, the White House estimated in 2015 that there were 500,000 open information technology jobs in the United States. Further, by 2020, there will be 1.4 million computer specialist job openings according to the U.S. Department of Labor. But projections show universities are not likely to produce enough qualified graduates to fill even 30% of these jobs.

Fields that require engineering expertise are also experiencing a talent shortage. According to the ManPower Group's 10th Annual Talent Shortage survey in 2015, employers globally report that engineering positions are the third hardest to fill and 35% of employers report that this difficulty is due to lack of available applicants. The U.S. Bureau of Labor Statistics reviewed research conducted on the job market for STEM-related fields and concluded that in the government sector, there is a general shortage of systems engineers and transient shortages of electrical and mechanical engineers with advanced degrees.

Of the top 25 occupations requiring a bachelor's degree in Colorado in 2014, five are in IT and two in engineering with all exhibiting positive projected growth rates between 1.9%-3.4% through 2024.

DU's Current Position in CO STEM Masters Degree Market

According to analysis of IPEDS data conducted by Meteor Learning on behalf of DU, DU had 15.1% share of the Masters market in the Boulder, Colorado Springs, Denver and Fort Collins markets in 2014. From 2009-2014, DU had higher growth than the market in the number of Masters graduates overall (3.1% DU vs 2.4% market). However, much of that growth took place from 2009-2012 (9%), but then declined by 8.8% in 2013 and 1.2% in 2014.

In addition, that growth has been mixed across different Classification of Instructional Programs (CIP). Specifically, DU lagged the market from 2009-2014 in growth of Masters graduates in the highest-growth STEM occupational areas including engineering (7.2% market vs. -0.4% DU), computer and info sciences (21.5% market vs. 7.4% DU), biomedical sciences (10.3% market vs -3.6% DU), physical sciences (8.4% market vs -7.8% DU) and engineering tech (4.3% market vs. -39.7% DU).

Market Opportunity in STEM Professional Masters Degree Market

According to a whitepaper written by the Executive Advisory Board entitled "Understanding the Changing Market for Professional Masters Programs," masters degree programs are expected to grow by 36% by 2022-2023, faster than any other level of degree. By 2022, masters degrees will account for 31% of all degrees awarded, up from 28%, and professional masters will account for this growth.

However, the growth in these professional masters will not be in traditional areas like business, law or education, but instead "niche programs that are customized to new and rapidly changing roles, such as cybersecurity, data analytics, and health informatics." Unlike traditional professional masters which rely on brand recognition, these niche programs attract students by connecting to industry in the region and preparing students to meet a particular industry need.

Description

The new suite of PMDs will be modeled in intent and organization after the MS in Cybersecurity degree launched in Fall of 2016. Like the MS in Cybersercurity, the PMDs are intended for early or mid-career professionals looking to pivot to in-demand, high paying careers. For the PMDs offered by the Computer Science Department, students may have a bachelor's degree in any discipline, but may be required to take prerequisite or "bridge" courses prior to beginning their chosen PMD program. For the PMDs offered by the Mechanical and Electrical Engineering Departments, an undergraduate degree in engineering from a reputable institution is strongly encouraged as many employers require it to be considered for engineering roles.

PMDs will be comparable in quality and technical depth as two-year Masters degrees currently offered at RSECS, but focused on experiential learning and skills needed to be successful professionally, rather than independent research and scholarship emphasized in traditional two-year Masters programs. The new suite of PMDs are designed to be completed in one academic year (nine months/three quarters) assuming prerequisite or "bridge" coursework is not required. PMDs will be offered throughout the academic year and students can anticipate a full schedule five days a week.

The intensive nature of PMDs require that all students be in residence in Denver in order to complete coursework on campus and an internship onsite with an industry partner all three academic quarters of the program. A liberal arts institution like the University of Denver provides unique advantages in that students will not only receive instruction in the technical foundations needed to be successful, but also how to think critically in any situation, ask the right questions and successfully work on diverse teams.

As these non-technical and experiential learning components differentiate the new suite of PMDs offered by RSECS from the multitude of educational offerings on the market, no coursework will be offered online. That said, PMDs will be priced competitively with comparable offerings locally.

The MS in Cybersecurity degree provides a good model in terms of organization, and by launching several PMDs in each discipline / department at the same time, it will be possible to provide courses that overlap and provide value for multiple student populations. For example, a course related to cybersecurity of mobile platforms could be an elective in both the Cybersecurity degree, and potentially a degree targeted at mobile / web development.

Feasibility Study

To test the market viability of this PMD strategic plan, RSECS will undertake a feasibility study in the first half of 2017. This feasibility study will include more detailed and degree-specific market analysis and forecasting for professional masters degrees. The feasibility study will include market research to identify target market, program preferences, willingness to pay, demand forecasts and positioning relative to competitors.

As part of this feasibility study, we will explore:

- Proposed new degree programs
- Historical and existing degree programs through local industry partners including Lockheed Martin
- Existing one-year academic, non-thesis masters degrees

Proposed new degree programs

Computer Science

- MS-Data Science
- MS-Internet of Things
- MS-Web Development

Electrical and Computer Engineering

- MS-Financial Engineering

Materials and Mechanical Engineering

- MS-Product Design

Historical and Existing Industry Partner Degree Programs

- Lockheed Martin
- United Alliance
- Northrop Gruman

Historical and Existing One-Year, Academic, Non-Thesis Masters

Computer Science

- MS-Cybersecurity
- MS-Computer Science
- MS-Computer Science Systems Engineering

Electrical Engineering

- MS-CpE Intelligent Information Design
- MS-EE-Electric Power and Energy Systems
- MS-EE-Microelectronics, Microsystems & Nanotechnology
- MS-EE-Modern Communications System Design
- MS-MSE-Mechatronic Systems Engineering

Materials and Mechanical Engineering

- MB-ENBI-Bioengineering
- MS-ENG- Engineering
- MS-ENG-Engineering with Concentration in Management
- MS-ENME-Mechanical Engineering
- MS-MTSC-Materials Science
- MS-NSE-Nanoscale Science and Engineering

Inclusive Excellence

Recruiting and hiring practices will be informed by the nascent RSECS IE strategic plan with a goal to create a more compositionally diverse and inclusive faculty and student body. In addition, steps will be taken to build a culture of inclusivity through all activities at RSECS, both in the classroom and in our interactions with one another.

DU 2025

One: Students Learning and Leading in a Diverse and Global 21st Century

S1 2: Enhancing and Expanding our Learning Environment

- Develop a cross-school teaching/learning environment to help faculty and students benefit from diverse teaching methods, combine different scholarly approaches, and create synergies on campus

S1 5: Preparing for Careers and Lives of Purpose

- Sustain a culture of design thinking with services and programs consistent with and responsive to rapidly changing global landscape

Two: Discovery and Design in an Age of Collaboration

S1 6: Project for Innovation, Entrepreneurship and Technology

- Serving the Rocky Mountain West as an incubator and launch pad for industry-educational partnership, helping Colorado to become known for encouraging and supporting this kind of activity.
- Encourage active and experiential learning through connections across campus and throughout the region, including maker spaces and partnerships with established organizations in industry and elsewhere. The incubator design could extend to co-ops and paid internships with industry or course-based relationships with companies

Three: Engagement and Empowerment in Denver and the Rocky Mountain West

SI 1: Collaboration for the Public Good

- Build on the strength of our community engagement programs, coordinated through the Center for Community Engagement & Service Learning to ensure that serving the public good is central to a DU education. This should include developing better ways to identify, promote and evaluate off-campus opportunities for students and faculty and ensuring that from orientation to graduation students understand that DU expects them to engage with, learn from and contribute to local and global communities.
- Expand our work, including developing our infrastructure, with communities and persons in need, providing human capital, intellectual and professional resources to offer services and partner with other organization to address social needs

SI 4: Partner in Innovation and Entrepreneurship in Denver

- Cultivate robust entrepreneurial culture tied to the public good that benefits faculty, staff and students, as well as Denver and the Rocky Mountain West. One step in this process is to learn more about and support the students and projects our faculty are conducting now.
- Expand collaborations with industry and trade, leveraging the resources of the schools and the Office of Institutional Partnership. We will engage with community partners and organizations across all sectors to provide relevant, contemporary expertise and services.

Research Clusters

Data Science-All Research Clusters

Internet of Things-All Research Clusters

Web Development-All Research Clusters (?)

Financial Engineering-?

Mechatronics/Robotics-Health, Mechatronics, Smart Cities, Machine Learning, Education

Product Design-All Research Clusters

MS DEGREES IN COMPUTER SCIENCE

MS in Data Science
Computer Science Department
Faculty Sponsor: Scott Leutenegger

Degree Description

The program is designed to provide students with a breadth of advanced knowledge in computer science, probability and statistics, data management and exploration, machine learning, as well as the emerging technologies that will gain in importance in the future.

Job Market

The appeal of a career as a data scientist is undeniable. In fact, the Harvard Business Review has deemed “Data Scientist” to be the “sexiest career of the 21st century.”

Salary-According to Burtch Works Executive Recruiting, the median salary of a junior data scientist is \$91,000 with managers earning well over \$250,000.

Growth-Burning Glass indicates that demand for data scientists increased 372% from 2011-2015.

Job Openings-In 2011, a report by McKinsey & Company estimated that there will be between 140,000-190,000 unfilled data science jobs in the United States in 2018.

Top Skills Listed in Job Descriptions- R, Machine Learning, SAS, SQL, Python, JAVA, Apache Hadoop, Big Data, Data Mining (Burning Glass)

Target Customer

The proposed degree is designed to be completely self-contained and assumes no background in computer science other than demonstration of analytical skills (judged by way of a good score on the Quantitative section of the GRE or GMAT) and evidence of mathematical abilities (calculus and above).

Competitive Analysis

As many education-related organizations have recognized the need for data scientists, competition in this space is fierce. many excellent universities have on-campus and online offerings:

National-Stanford, Carnegie Mellon, University of Maryland, NYU, UVA

Regional-UC Boulder and Denver, CSU, Regis

Online-UC-Berkeley

Coding Academy-Galvanize U

Cross-Disciplinary Opportunities: Several disciplines across the university would benefit from data science including psychology, economics, social work, education and public policy amongst others.

Distinction within DU Context: The MS in Data Science is different form the MS in Business Analytics at Daniels College of Business as business analytics focuses on what has happened whereas data science is focused on predicting what could happen. Data Science predicts and mitigates uncertainty in data, whereas Business Analytics looks at existing data to draw conclusions and insights. The RSECS program will take advantage of expertise unique to the computer science department to emphasize mathematical, theoretical and programming aspects in its curriculum. Further, students will not only be able to use data to drive business decisions but also address grand social challenges.

Implementation Plan

Launch Year: Fall 2017

Curriculum: See degree proposal document

Capacity Needed: 10 first year, steady-state cohort of 20 students is desired.

MS in Internet of Things
Computer Science Department
Faculty Sponsor: Ramki Thurimella

Degree Description

The MS in Internet of Things (IoT) degree is designed to provide students with cross-disciplinary knowledge in electrical engineering, electronics, mechanical engineering, and computer science. IoT devices can generate data on which data science principles and machine learning techniques can be applied for increased automation.

Job Market

The growing market of IoT-connected devices in combination with the growing frequency of cybersecurity incidents related to the connected devices means that professionals who understand its many complexities will be in high demand. Cisco has already begun creating roles for IoT specialists and managers, and predicts the need for IoT know-how will increase.

Salary-Pursuing a career connected to the IoT can take many different paths. While an average or median salary is difficult to pin down, the job titles (developers, information security analysts, etc.) that frequently interact with the IoT are in high demand and command high salaries.

Growth- According to the Gartner Group, the incremental market value of new services yielded by the Internet of Things will exceed \$1.9 trillion globally by 2019. By 2020, the installed base of smart units linked to the IoT will total more than 26 billion items.

Job Openings- According to a report by the Corporate Executive Board in 2015, the fastest growing Internet of Things (IoT) job positions include systems software developers (215% growth in the past year), information security analysts (113% growth), and computer systems engineers (110% growth). General Electric has advertised 2,104 jobs looking for skills needed to support their Industrial Internet initiative in the last two years. The hiring demand for commercial and industrial designers with IoT skills has risen by 322% since 2014. Employer demand for product engineers with skills related to the Internet of Things has increased by nearly 275% since 2014.

Top Skills Listed in Job Descriptions- circuit design, microcontroller programming, AutoCAD, machine learning, security infrastructure, big data, electrical engineering, security engineering, Node.js, GPS development (CIO.com)

Target Customer

Anyone with a technical aptitude interested in building applications that will have significant impact may pursue the MS in IoT. The proposed degree is designed to be completely self-contained and assumes no background in computer science other than demonstration of analytical skills (judged by way of a good score on the Quantitative section of the GRE or GMAT) and evidence of mathematical abilities (calculus and above).

Competitive Analysis

There is not as much competition in this space. Excellent opportunity for DU to get the “first mover advantage.” MIT has \$500 online [professional certificate program in IoT](#) and Coursera has a [concentration in IoT](#). However, many overviews of the industry point to Data Science degrees for careers in IoT. Marketing an MS in IoT specifically could hold strong appeal. There appear to be IoT degrees in the UK that may be worth examining for program structure and curriculum, but not likely competitors.

Cross-Disciplinary Opportunities: By its very nature, IoT is interdisciplinary bringing together not just computer science and engineering, but also business, design, sociology, law and ethics.

Distinction within DU Context: No comparable degrees exist at DU.

Implementation Plan

Launch Year: Fall 2018

Curriculum:

Capacity Needed: 10 first year, steady-state cohort of 20 students is desired.

MS in Web Applications
Computer Science Department
Faculty Sponsor: Scott Leutenegger

Degree Description

The program provides an in-depth knowledge of web design and web development through hands-on instruction. Students will develop desktop and mobile applications. Students will be able to demonstrate knowledge and practical use of web application development languages and proficiency in web languages.

Job Market

According to [US News & World Report](#), Web Developers rank #3 in Best Technology Jobs and #4 for Best STEM jobs.

Salary- The BLS reports that Web developers made a median salary of \$63,490 in 2014. The highest-paid in the profession earned \$112,680, while the lowest-paid earned \$33,790 that year. Computer systems design and information services employ the largest share of Web developers in the field.

Growth- [The Bureau of Labor Statistics](#) projects about 27% employment growth for Web Developers by 2024. The expansion of e-commerce is expected to be the main driver of Web developer job growth in the next decade. As more companies offer or expand their online retail presence, more Web developers will be needed to build the websites visited by consumers to purchase their favorite products.

Job Openings- The App Association estimates that there are nearly 250,000 job openings in Web App Development.

Top Skills Listed in Job Descriptions- CSS, HTML, Github, FTP, Bug testing, javascript

Target Customer

Prospective students would not be required to have a computer science background, but may be required to pass a pre-assessment or

Competitive Analysis

Several comparable degree programs exist.

Cross-Disciplinary Opportunities:

This degree could coordinate with marketing to better understand how customers use web applications.

Distinction within DU Context: Although University College offers a degree in Web Design and Development, the RSECS degree will be on campus, in person and facilitate connections between students and industry. Also, there may be some overlap with courses in Emergent Digital Practices but there is a significant amount of coursework grounded in art in the EDP MA and MFA.

Implementation Plan

Launch Year: Fall 2018

Curriculum:

Capacity Needed: 10 first year, steady-state cohort of 20 students is desired.

MS DEGREES IN ELECTRICAL ENGINEERING

MS in Financial Engineering
ECE Department
Faculty Sponsor: Margareta Stefanovic/Kimon Valavanis

Degree Description

This is a multidisciplinary program that applies engineering methodologies and applied mathematics knowledge to problems in finance. Financial theory, traditionally the core approach to this problem, is enhanced with engineering tools such as optimization, system theory, optimal control, dynamic programming, stochastic processes, and computer programming, to more successfully tackle the ever-increasing complexity of the problems in the financial sector.

Job Market

Salary-Average salary for a quantitative analyst is \$100,000k.

Growth

Job Openings- Trader, risk manager, quantitative analyst. Industries: Banks, insurance companies, security industries, regulatory agencies, trading companies. Indeed.com lists 44705 full-time positions for the financial analysts job description.

Top Skills Listed in Job Descriptions

Target Customer

Prospective enrollees will have a BS background in engineering, computer science, applied mathematics, or physics. Those with an undergraduate degree in Business or Economics will be considered provided they have adequate background in linear algebra and probability.

Competitive Analysis

Residential: USC, NYU, UIUC etc. offer similar programs in financial engineering. The great majority of other schools focus on the financial aspect only.

Cross-Disciplinary Opportunities

This is essentially an interdisciplinary program: it lies at the intersection of Engineering , Business and Economics.

Distinction within DU Context: Traditional Masters programs in Finance exist at other major schools in the state. This would be the first program in Colorado to prepare future professionals with a solid understanding of engineering and math to outperform the competition in the finance industry.

Implementation Plan

Launch Year-Fall 2019

Curriculum-About one half of the curriculum will be in the engineering and computer science areas, such as Probability and Statistics for Engineers; Optimal Control; Optimization; Detection and Estimation Theory. The other half will include courses from Economics, Business, and Finance departments (e.g., Corporate Financial Theory, Investments, Financial Risk Management etc.).

Capacity Needed-10 first year, steady-state cohort of 20 students is desired. No new courses/faculty hires are needed. The program can be established as soon as a collaborative plan among RSECS, DCB and the Department of Economics is laid down.

MS in Mechatronics
MME/ECE Department
Faculty Sponsor: ?

Degree Description

This MS in Robotics program is designed to integrate complex systems requiring knowledge in computer science, computer engineering, electrical engineering, and mechanical engineering.

Job Market

Robotics are making manufacturing processes more efficient and less labor intensive. Industrial robots are common in auto manufacturing.

Growth- In 2014, PwC noted that job opportunities to engineer advanced robots and systems increased by 35%. Half of US Manufacturers use robots and with a quarter of a million working in US factories in 2013. International Data Corporation predicts that spending on robotics and related services will grow at a compound annual growth rate of 17% globally reaching \$135.4 billion in 2019. BCG predicts that by 2025, the portion of tasks completed by robots will near 25% for all manufacturing industries worldwide, up from the current 10%.

Job Openings- There are several dozen robotics companies in the Rocky Mountains including MSI Tec, Wolf Robotics and Colorado Automation and Design.

Top Skills Listed in Job Descriptions

Target Customer

Individuals with a bachelor's degree in engineering or computer science who desire to re-tool and change careers into the diverse field of mechatronics and robotics. These individuals are typically interested in pivoting into an artificial intelligence, machine vision, automation, sensing and control systems and expert systems.

Competitive Analysis

Carnegie Mellon, University of Michigan, NYU, Northwestern, WPI, Colorado School of Mines, Florida International University, Georgia Tech, Santa Clara, University of Utah

Cross-Disciplinary Opportunities

Already at DU, the work in the research of Mechatronics and Robotics is cross-disciplinary, and not just within engineering and computer science but other research disciplines like aging and education.

Distinction within DU Context: No comparable degrees exist at DU.

Implementation Plan

Launch Year: Fall 2018

Curriculum:

Capacity Needed: 10 first year, steady-state cohort of 20 students is desired.

MS DEGREES IN MECHANICAL ENGINEERING

MS in Product Design
Mechanical and Materials Engineering
Faculty Sponsor: Mike Caston

Degree Description

The MS in Product Design will be project-based and grounded in design thinking. With experiential learning at the core of the curriculum, candidates for the MS in Product Design will choose a focus area at the outset and focus their education on designing solutions for one of society's grand challenges.

Job Market

There is a great need for individuals with the technical skills necessary to design solutions that address social challenges. These individuals will be required to work alongside professionals in the areas of public policy, international development, medicine, education and business. Students will be prepared for exciting careers at organizations like IDEO.org, D-Rev or Design that Matters or foundations like the Bill & Melinda Gates Foundation. We would encourage students to consider building similar organizations in Colorado or striking out on their own as entrepreneurs.

That said, the individual drawn to Product Design will have a different set of motivations, and will be more interested in applying their design-thinking methodology to addressing grand social challenges rather than working in a particular industry, achieving a certain job title or earning a certain salary. Individuals trained in design thinking may hold more traditional titles like Business Designer or Design Researcher or combine their interest in design with other skills and passions, such as coding, social impact or entrepreneurship.

Target Customer

Prospective students would have an engineering or computer science undergraduate degree. In contrast to a Master's of Science in Mechanical Engineering which provides deeper technical skills preparing students for a career in Engineering, candidates for the MS in Product Design would be interested in understanding the broader context of the challenges we face and how design thinking can address these challenges.

Competitive Analysis

Stanford offers a two-year MS in Engineering, Design Impact through its Mechanical Engineering department; Northwestern offers an MS in Engineering Design Innovation through the Segal Institute of Design; California College of the Arts MS in Industrial Design

Cross-Disciplinary Opportunities

While students will be required to complete courses in design fundamentals offered by engineering and computer science faculty, they will be encouraged to enroll in courses outside of RSECS that relate to their focus area. For example, a student focusing on solar energy would be encouraged to explore courses in economics relating to energy markets and subsidies. A student exploring the use of gaming in education could explore courses at Morgridge School of Education to better understand teaching methodology and child development.

Distinction within DU Context: Context-No other school is in a position to offer design-focused curriculum. The MFA in Emergent Digital Practices may have some overlap but ultimately produces graduates with different goals than those focused on product design.

Implementation Plan

Launch Year: Fall 2019

Curriculum: Design-Thinking, Rapid prototyping, year-long human-centered design project, experiential learning, Interdisciplinary courses with other schools

Capacity Needed: 10 first year, steady-state cohort of 20 students is desired.

Appendix J. Research Strategic Plan

INTRODUCTION

This plan outlines strategic areas for research and development growth with the aim to increase RSECS visibility, improve reputation, attract major external funding and establish RSECS as a key player within the State of Colorado, the Rocky Mountain Region and the Nation. Significant challenges in society are addressed primarily through the development of world-renowned faculty and facilities that serve as amplifiers to perform high impact basic, applied and transformative research and development.

We will align our capabilities to address two mega world challenges with the intent of serving the public good. Our research will also inform our teaching across the undergraduate and graduate programs. This focus will aid us in advancing work that meets our School's mission and vision and the University's IMPACT 2025 strategic plan.

Experience shows that bringing together faculty with complementary and overlapping expertise may lead to highly successful and impactful funded research and development and support the strategic investment of resources to create such high-quality research expertise, laboratories and computational facilities.

Recommended faculty hires

Health: Advancing Biomedical Devices and Technologies – 5 faculty hires

Robotics – 3 faculty hires

Smart City – 5 faculty hires

Cyber Physical Security – 3 faculty hires

Artificial Intelligence – 3 faculty hires

19 total new faculty hires

Our strategic focus leverages:

- Already developed, high visibility, current research strengths within RSECS that have demonstrated continuous success to date, but require additional investment in faculty hires and upgraded infrastructure to not only remain competitive, but to also be well-respected and well-recognized 'research differentiators' nationally and internationally.
- On-going research activities that are successful and have demonstrated great potential of growth, but require significant investment in new faculty hires and infrastructure to capitalize on existing talent and to create the required critical mass for sustainable success.
- Recent initiatives where RSECS can be a major player and differentiator. These areas require major investment in human capital and resources, short- and long- term, to build credibility at the national level that will lead to recognition and success.

These areas are related to, and are in sync with, National Academy of Engineering (NAE) Grand Challenges for Engineering, the United Nations' Sustainable Development Goals, and the DU Impact 2025 Strategic Plan.

1. HEALTH: ADVANCING BIOMEDICAL DEVICES AND TECHNOLOGIES

Introduction

"Better health is central to human happiness and well-being. It also makes an important contribution to economic progress, as healthy populations live longer, are more productive, and save more."

- World Health Organization

With the growing elderly population, marked by the projected doubling of the 40 million people over the age of 65 by the year 2030 (U.S. Department of Health and Human Services), and the increasing economic burden of health care, society needs innovative and cost effective treatments, and the next generation of technical thought leaders.

The Ritchie School of Engineering and Computer Science will lead the development of new technologies for health care. These efforts will build on strengths in biomechanics, cancer detection, neuroengineering and social robotics, and leverage world-class equipment, like the high-speed stereo radiography system for sub-mm measurement of joint motion. Health-related research is strategically aligned with the translational research performed in DU's Knoebel Institute for Healthy Aging and with product innovation and entrepreneurial activities in DU's Project X-ITE.

The last significant strategic differentiator is that bioengineering and health-related research attract diverse populations. Bioengineering is the fastest growing engineering discipline and working on problems that help people resonates with women and underrepresented minorities. The U.S. Department of Education predicts that the largest increase in science, technology, engineering and mathematics (STEM) jobs will be in Biomedical Engineering, 62% from 2010 to 2020.

Current directions in health are toward personalized medicine and health monitoring technologies. Personalized medicine involves the creation of custom treatment plans or implants, while health monitoring, with devices like Fitbit or Apple Health, provides access to new levels of patient data and opportunities for feedback. We support faculty hiring and infrastructure development in areas complementing current expertise, specifically: medical device design, health monitoring / wearables, data science (informatics and computer-aided diagnosis), biomaterials, and neuroengineering. In this way, the Ritchie School will be well positioned to design new additively-manufactured medical devices, create algorithms where collected data informs clinical decisions, train new engineers and leaders, and pioneer new therapeutics and technologies promoting a healthy population.

Overview

Health-related research conducted at DU/RSECS is themed around engineering solutions to major health problems. MME faculty research is clustered around Orthopaedics, with expertise in computational

modeling, in vivo data collection, and in vitro/cadaveric measurements related to joint replacement and cardiac devices. ECE faculty members are working in neuroengineering, social assistive robotics related to autism and elderly with depression and dementia, as well as in cancer detection, and sensing technologies for aging populations and patients with Parkinson's disease.

These health problems affect millions of people each year and the numbers are expected to continue to rise with the growing number of elderly people. For example, each year 12.7 million people discover they have cancer and 7.6 million people die from the disease (Centers for Disease Control and Prevention). There are more than 1 million joint replacements in the U.S. each year (American Academy of Orthopaedics Surgeons) and revision rates remain at 5-10% at 10 years. The U.S. Department of Health and Human Services reports that the number of people over the age of 65, currently at roughly 40 million, is set to double by 2030. In addition to the aging population, there has been a dramatic increase in human health monitoring across all populations, from Strava, which measures running and cycling activities to Fitbit or Apple health, which report activity levels. Further, bioengineering is the fastest growing engineering discipline, with rises observed in both education and jobs to support the health industry. The U.S. Department of Education predicts that the largest increase of science, technology, engineering and mathematics (STEM) jobs will be in Biomedical Engineering, 62% from 2010 to 2020. Health related research, with links to the elderly population and human health monitoring, are integrally linked to the Knoebel Institute for Healthy Aging and Project X-ITE.

RSECS currently has research strengths in health-related areas and the proposed health initiative will leverage existing faculty experience and facilities. The faculty in orthopedic biomechanics has been successful in securing industrial and federally (NSF, NIH) funded projects (PIs: Rullkoetter, Shelburne, Davidson, Laz, research expenditures of 4.35 million since 2011). The Human Dynamics Lab has a unique high-speed stereo radiography system, one of 6 in the world, which allows for imaging of joint motions during dynamic activities. Dr. Mahoor has research expenditures of \$2 million since 2011 and his projects in social robotics are being used in the clinic to help patients with dementia and depression. His work in autism has been featured on NPR and in Forbes. These research efforts expand DU's national and international reputation, which is one of the measures used in University rankings.

Hire Faculty in Key Areas of Collaboration – Total of Five (5)

It is proposed to hire one (1) faculty member per year, total of five (5), in health over the next several years. New faculty will leverage and bridge current expertise; new faculty home department will be determined accordingly. The areas of expertise span:

- *Biomedical device design / Innovative technology for therapeutics.* This area involves working closely with clinicians (on-site observations) to identify opportunities to improve current processes, devices and treatments. There is potential to develop sensors and smart devices for use with patients. Customizable device workflows can leverage additive manufacturing. While device dependent, technical engineering challenges can be related to power, miniaturization, data interfacing, etc. This area has strong links with Project X-ITE and high potential to develop IP. The home department could be either MME or ECE.
- *Human health monitoring / wearables.* From the Fitbit to the Apple Health apps, the collection of data monitoring the body has become wildly popular. At the same time, the measurements and algorithms remain somewhat limited. There are opportunities to improve the accuracy of sensing and the algorithms in order to have the data be more useful in informing clinical decisions. Can a smart phone tell when one needs to visit the doctor or have a knee replaced? In wearables, sensors have potential to measure emotion or control a prosthesis. The home department could be either ECE or CS.

- *Data Science*. Advancing health-informatics is one of the 14 Grand Challenges identified by the National Academy of Engineering. The availability of health data (from above human health monitoring, or medical imaging) is at unprecedented levels. There are many opportunities to streamline the processing of data with the potential to improve/customize patient treatment and extend research models to the clinic. Expertise in this area could involve machine learning, image processing and computer vision (automated segmentation of structures from MRI, pose matching in radiographic imaging) and computer-aided diagnosis. The home department could be either ECE or CS.
- *Biomaterials*. The behavior of human tissue is quite complex. Understanding the mechanical behavior of ligaments, blood vessels, and other tissues are critical to advancing the field of biomechanics and in developing devices to interact with the body. This research area involves both characterizing the properties of human tissue (non-linear, visco-elastic) and developing new materials that can mimic the properties and be compatible with the body. There are strong connections with current modeling and experimental efforts, and to the proposed device and bio-sensing areas. The home department should be MME.
- *Neuroengineering*. Reverse-engineering the brain is another of the 14 NAE grand challenges. In terms of applications, reverse-engineering the brain can play a critical role in addressing health problems related to the nervous system. Reverse-engineering the brain has also technological applications, such as the design of smart autonomous-systems and of efficient machine-learning algorithms. These applications provide a natural synergy with Area 2, Robotics, discussed below. The home department could be ECE or CS.
- Inclusive excellence: The current generation of students is motivated to work on and solve “big” problems and this area will provide projects with the potential to impact and improve the quality of people’s lives. We strongly support hiring faculty, who are female or from underrepresented populations, to help build these areas, while also serving as positive role models. A diverse faculty will help to create a culture that attracts a diverse student population.

Build a research community: courtesy appointments and industry named fellowships

Success in the health area requires strong partnerships with clinicians, and also industry. The faculty, who have been successful in these areas, have reached out and developed collaborations with area clinicians (e.g. Colorado Joint Replacement, Colorado Neurological Institute, Kaiser Permanente). While several clinicians have courtesy appointments, they are offered adjunct titles, that last just 1 year. We should try to provide a more prestigious title (e.g. clinical professor) and engage this group as valued members of our community (participating in events, seminars, etc.).

On the industry-side, we should seek support for named graduate fellowships. In this mechanism, the company will provide support for a graduate student interested in performing research in a related area. For an MS student, the fellowship could involve spending the summer working as an intern at the company. This should be considered as part of the larger effort to develop industry partners / advisory board. We see this activity as more of a scholarship than a sponsored research project, although the industry experience could also be included in sponsored projects to promote tech transfer.

Invest strategically in equipment and facilities

While we recognize faculty have a responsibility to support their research activities, there are some pieces of equipment that are considered basic for performing research. Examples include: shared computational resources, materials characterization (e.g. microscope, MTS load frame, scanning electron microscope), etc. As such, federal agencies and industry partners are not interested in providing funding for them. We also note, that most of the school's investments in equipment over the past 5 years have been to support undergraduate education. Mechanisms need to be available to enable investment in basic equipment needed to perform research, either through school or university-level investments, indirect costs, philanthropy, or remaining balances on fixed price contracts.

Improve web presence

Faculty do not receive administrative support to develop research websites, and as a result, center and laboratory web pages are in a wide variety of formats. Some faculty use non-DU sites. We need to have a strong, consistent web presence to promote our activities. They should be prominently highlighted on the RSECS homepage.

Many investigators are also required to share data with the research community at large. RSECS should develop a standard way of hosting this kind of data, perhaps through Digital Commons. Note: Stanford has positioned themselves as the “go to” repository for bio-related computational models (simTK.org); their site hosts lots of work performed at other institutions.

Current faculty/researchers in the Health area

MME: Paul Rullkoetter (computational biomechanics), Peter Laz (probabilistic biomechanics), Bradley Davidson (human movement), Ali Azadani (cardiac biomechanics), Chadd Clary (experimental biomechanics), Kevin Shelburne (research professor, musculoskeletal modeling). ECE: Mohammad Mahoor (social robotics and machine learning), Jun Zhang (sensing), K.-D. Kim (robotics), H. Ogmen (neuroengineering).

Competitors

Peer and competitor labs can be identified nationally and internationally for each of the individual research labs. While the health and biomechanics fields are quite broad, we have focused our research efforts in areas where we can be distinctive and unique. Further, the faculty that has been developed allows us to collaborate internally in a way that historically would have been performed across universities.

In Orthopaedic biomechanics, industry collaborators have found it helpful to have the set of in vivo, in vitro and modeling capabilities all in one location. The uniqueness of the stereo radiography capabilities combined with other motion measurement and computational modeling is a clear strength and has helped us forge strong partnerships with industry. We have embraced collaborations with area leaders: University of Florida, Flinders University (Australia), Ramboud University (Netherlands). Other competitors in biomechanics broadly are University of Auckland (computational modeling), University of Utah (shape modeling), MIT (fluoroscopy), Pittsburgh (fluoroscopy) and University of Leeds (UK, wear testing and modeling).

Other Information

Partners and Collaborators: Colorado Joint Replacement, Craig Hospital, Colorado Neurological Institute, University of Colorado School of Medicine (Rehabilitation program). Potential new partners: Denver Health, DU's Daniels College of Business, Medtronic.

Current funding sources: NSF, NIH, DePuy Synthes, Ossur, Nike. Potential new funding sources: Zimmer Biomet Spine, Medtronic.

Interesting models: University of Minnesota Medical Device Center has an innovation fellows program, which provides an immersive educational and product development experience in medical device creation. <http://www.mdc.umn.edu>.

2. ROBOTICS

Introduction

Robotics, in general, is witnessing exponential growth, worldwide, and will continue to be on the forefront of cutting edge technologies in the years to come, particularly because robotics applications span an unusually large spectrum of domains. Robotics, as a research discipline and as a specific application, relates to almost all of the 14 NAE Grand Challenges. R&D ranges from Space Robotics to Medical and Bio-inspired Robotics, Assistive and Social Robotics, Micro- and Nano- Robotics, Unmanned Robotic Vehicles and Unmanned Systems, to name but a few distinct categories. Robotics is also the backbone of Automation, in which robots and robotic systems are tasked to complete the dirty, dull and dangerous tasks, instead of humans. Under the new doctrine, robots are seen as teammates assisting humans and working with humans rather than replacing humans in the job floor environment. It is claimed that 'robots are here to stay' and this is a true statement.

Overview

Since the early 1960's, robotics has evolved from the traditional mechanical manipulator to also include (in addition to the above mentioned areas) Mechatronic Systems, Embedded Systems and Cyber Physical Systems (CPS). As the complexity of engineering systems increases, the new concept of 'system of systems' becomes a design principle and constraint, which includes multi-robot teams that work synergistically to complete complex missions that one individual robot cannot complete.

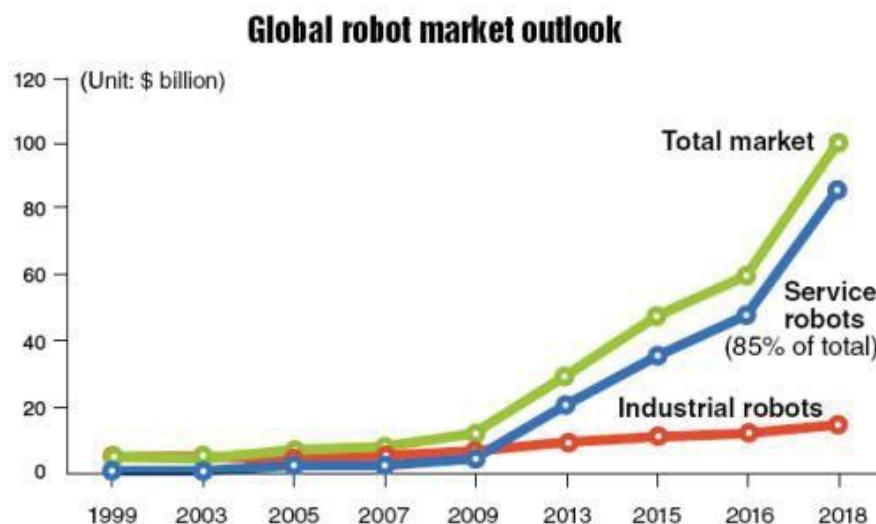
A unique thrust area within robotics is unmanned systems. The term 'unmanned systems' refers to all types of underwater, sea-surface, ground and aerial robotic platforms. Although at times controversial, there is nothing 'unmanned' in 'unmanned systems'; such systems require (on average) four (4) operators to control them. Unmanned systems simply refer to systems that have no operator onboard – operators monitor and control them from a distance.

Research and development in Robotics within RSECS centers around two thrust areas: service robotics and unmanned vehicle systems. Objectives of on-going and in-progress research activities focus on: i.) Developing Co-Robots/Companionbots as assistants to individuals with social or mental disabilities (including children with special needs, and the elderly with depression, dementia), and, ii.) Developing the next generation of 'complete' unmanned systems endowed with attributes of autonomy and autonomous performance. It is of importance to state that orthogonal research and development to Co-Robots

(Companionbot, service robotics) is bio-inspired robotics and bio-kinetics / biomechanics (including prosthetics and orthotics) and, in general, medical robotics.

The Financial Times state that “Rise of the robots is sparking an investment boom” and “Global influx of machines set to open one of the hottest new markets in tech”. It is also stated that after growing at a compound rate of 17 per cent a year, the robot market will be worth \$135bn by 2019, according to IDC, a tech research firm, <https://www.ft.com/content/5a352264-0e26-11e6-ad80-67655613c2d6>. Figure 1 depicts the global robot market outlook. The service robot/personal services component is increasing exponentially compared to the relatively flat industrial robot component market. This trend is expected to continue, thus, the emphasis to develop Co-Robots is well justified. On the other hand, focusing just on the Unmanned Aerial Vehicles (UAVs) market, Figure 2 illustrates that, according to the Teal Group, UAVs is the most dynamic growth sector of the world aerospace industry this decade. The Teal Group states “New unmanned combat aerial vehicle programs, commercial, and consumer spending all promise to drive more than a tripling of the market over the next decade.” It is also stated that "...coverage of the civil UAV market continues to grow with each annual report, mirroring the increase in the civil market itself", and, “[the] 2015 UAV study calculates the UAV market at 72% military, 23% consumer, 5% civil cumulative for the decade. Of the three areas, civil UAVs grow most rapidly over the forecast period as airspace around the world is opened, but it grows from a very low base.” Figure 3 shows the difference between total direct spending versus economic impact. Again, the emphasis to develop the next generation, NextGen, of UAVs endowed with autonomy attributes is well justified.

In addition, according to a research study by [Tractica](#), annual shipments of consumer and service robots (e.g. vacuum robotic, lawn mowers and pool cleaners, social robots) will increase from 6.6 million units in 2015 to 31.2 million units, worldwide, by 2020. It is estimated a total of nearly 100 million consumer robots shipped during that period. According to the report, "the next 5 years will set the stage for how these robots could fundamentally transform our homes and daily lives." All these reports and evidences strongly support that the timing is right to invest in robotics at DU and build on our current capabilities and strength and be a lead world-class research team in this area.



Worldwide robot industry market forecast

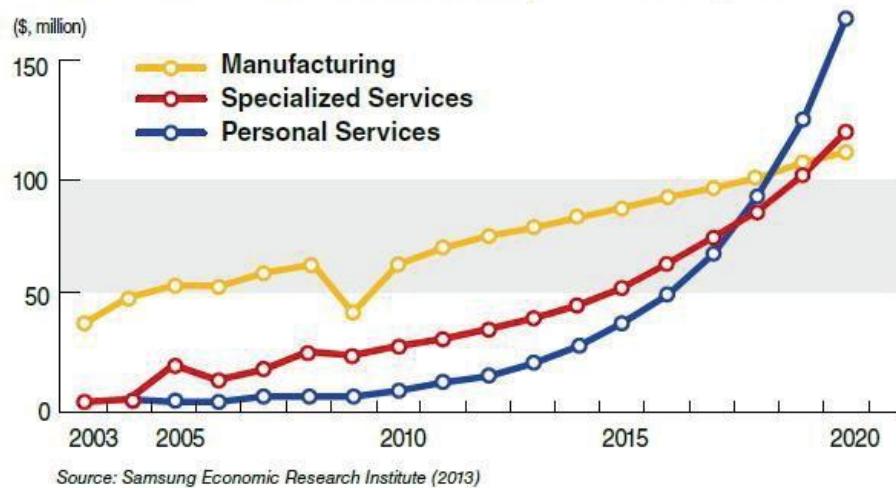


Figure 1: Global robot market; service and industrial robots.

World UAV Budget Forecast

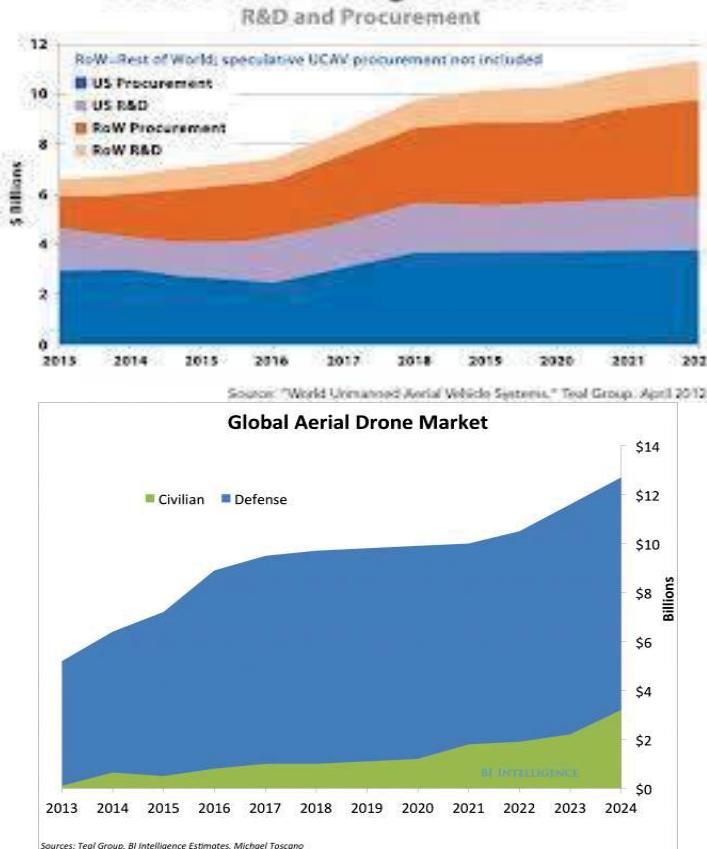


Figure 2: UAV budget forecast.

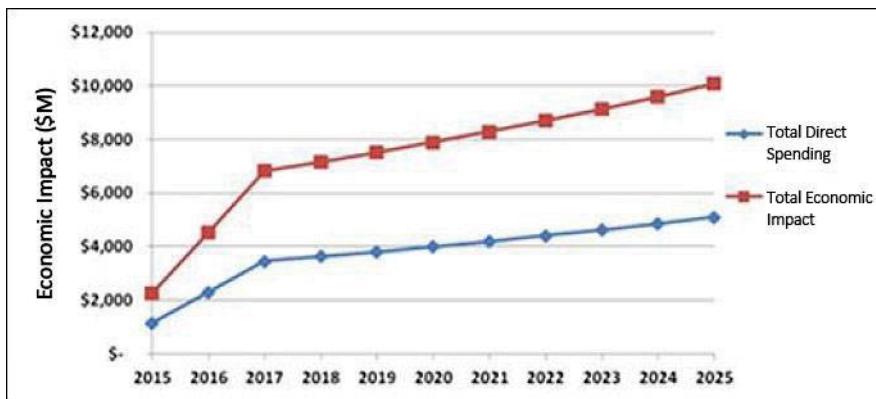


Figure 3: UAV total direct spending versus total economic impact.

Current faculty/researchers in the Robotics area

Since 2008, research in Co-Robots and Unmanned Systems within RSECS is growing, and robotics has emerged as a strategic focus area of the Ritchie School of Engineering and Computer Science. Robotics is also an area in which there are close to the needed ‘critical mass’ faculty members; Drs. K. Valavanis, M. Mahoor and M. Rutherford (CS, courtesy appointment in ECE) were hired in 2008 (September 1). Dr. J. Zhang was hired in 2011, Dr. K.D. Kim was hired in 2013 and Dr. M. Stefanovic was hired in 2014. Productivity and success is evidenced by external competitive awards (NSF-MRI, NSF Grants, DOE, Industry grants, SBIR), patented technology and a long list of archive and original publications. Faculty members have established national and international reputation in this area and they are involved in numerous international activities (conference organization, forums, panel discussions, briefings, book publication, Editors, Editors-in-chief, etc.); ECE/CS faculty have launched the annual International Conference on UAS and they are members of the IEEE Robotics and Automation Society Aerial Robotics and Unmanned Aerial Vehicles Technical Committee that received first prize award, worldwide, for activities in 2015-16. In addition, faculty have published the “Handbook on UAVs”, Springer, now in its 2nd Edition, along with other books that have also been translated in Chinese. Junior faculty are starting to demonstrate ability to attract competitive funding, in addition to receiving NREL funding.

Current Funding

Since 2011, research expenditures in Social Robotics are close to \$2 million, expenditures in Unmanned Systems are close to \$2.2 million, for a grand total of expenditures approaching \$4.5 m. Adding more faculty members with complimentary expertise (as justified below) will only strengthen the team and increase funding. Note that there is major overlap with research and development activities in the Health area (see above), thus, there will be continuous synergy and joint collaboration among faculty.

Hire Faculty in Key Areas of Collaboration – Total of Three (3)

It is proposed to hire three tenure-track faculty members at the Assistant Professor level. New faculty will leverage and bridge current expertise; new faculty home department will be determined accordingly. The areas of expertise span: Mechatronics, Robotics, Unmanned Systems, CPS, and Aeronautical Engineering. Search will focus on candidates with a strong mathematical modeling and experimental background in robotics and machine learning and artificial intelligence, as well as in CPS, embedded

systems, control system theory, and aeronautics, who will be able to interface with the rest of the robotics group and start producing immediately. Although the ‘candidate market’ appears to be diverse, the focus will be on recruiting qualified individuals who understand current challenges and open research questions, understand how industry works and how it prioritizes R&D. Further, qualified individuals should be capable to act as liaison/interface between the theorists and more research applied faculty to optimize the “concept-basic research-applied research and development-prototype system” cycle that is followed by the robotics group in RSECS. The home department of the new faculty could be either ECE or CS or MME.

Financial Justification: Hiring three faculty members in robotics provides opportunities for research revenues through collaboration with the current team and through new research activities to be enabled. It is realistically expected that each new faculty could increase research funding by an average of \$200K annually, for a combined total increase of \$600K annually. This is based on the fact that funding in Robotics initiatives, at the national level, is solid and it will remain at the same level – although likely to increase – in the future. Further, in addition to the direct research funding, it is emphasized that there is a significant market for: 1) offering 3-5 days’ short courses to practitioners and researchers (GTRI charges \$1,500.00 / registration); 2) offering Certificate Degrees (5 courses) in Unmanned Systems; 3) using Unmanned Systems Research Institute (DU²SRI) facilities for system/sensor or UAV prototype evaluation (companies frequently need such facilities). Revenue from the above mentioned activities could reach an estimated \$50K annually, excluding tuition for the offered Certificate Degree courses, which will constitute a direct revenue to RSECS. Establishing a ‘presence’ in unmanned systems, will also result in closer collaboration with the Colorado Aerospace Industry, a resource that has not been tapped as yet.

The starting salary of a new hire will be about \$105K (for nine months). Startup needs for each new hire, in addition to competitive salary, should include \$200K in equipment needs, two-year summer support and funding for 2 GRAs – this is the normal package.

Equipment / Space Needs: The new building has allocated lab space to Unmanned Systems / Mechatronics / Robotics. There will be no space requirements for the new faculty; any new equipment will also be housed in the already allocated space in the new building.

Teaching Considerations: Each new faculty member will teach 3 courses per academic year for the probation period. This being the case, there will be no need for additional faculty to cover programmatic needs.

The timeline for posting an ad and interviewing candidates should start as early in the Spring Quarter as possible. The robotics group already has several qualified candidates in mind, and are confident that an excellent candidate pool will be generated to choose from. Prior tenure-track searches have yielded between 85-280 applicants, but in this case the target will be on specific individuals who will be able to start contributing from day one at DU. The pool of candidates will include existing Assistant Professors, Post-Doctoral Fellows, Research Scientists and PhD students of major Tier I institutions and federal labs, already exposed to the culture of aggressive research and proposal writing.

Inclusive excellence: As also stated in the Health area, the current generation of students is motivated to work on and solve “big” problems. Robotics is the perfect candidate area to provide such projects with the potential to impact automation, manufacturing, productivity, and also improve the quality of people’s lives (social robots). We strongly support hiring faculty, who are female or from underrepresented populations, to help build these areas, while also serving as positive role models. A diverse faculty will help to create a culture that attracts a diverse student population.

Professionally Designed Web

A professionally designed web reflecting research and development activities in Robotics with links to the individual pages of faculty, their list of publications, students, professional involvement, etc., will certainly contribute to establishing a strong, consistent web presence to promote our activities. The 'web' issue has been an on-going challenge in RSECS and DU, full of inconsistencies, difficult to navigate, non-user-friendly, adversely impacting reputation. The web challenge should be addressed and resolved as a whole within RSECS. This will increase and improve visibility and will help attract more / better students.

Partners

The group has established solid collaborations with top 50 university research groups (GaTech, Purdue, UPenn, Notre Dame, Minnesota, UNLV), international universities (Politecnico di Torino, Universita Politecnica delle Marche, University of Seville, Technical University of Crete), NASA Langley, Lockheed Martin and Raytheon, and the private sector, and has produced licensed technology used by companies (i.e., IRIS, an Alaska based company). Strengthening such collaborations through strategic planning will result in major funded projects. Partnerships will continue and additional collaborations will be initiated. For example, faculty are members of UAS Colorado, AUVSI Rocky Mountain Region, and Colorado Aerospace Coalition.

Competition

It is obvious that almost every college/university in the U.S. has a robotics component. Most of the universities/colleges offer robotics-courses, and close to 50 U.S. universities have world-wide known research programs in robotics. Top schools include MIT, Berkeley, Stanford, Purdue, CMU, Georgia Tech, U of Minnesota, to name but a few colleges. However, RSCES can be the unique 'differentiator' by focusing on Co-robots and Companionbots to improve quality of life of the elderly and the needy. Collaboration with other groups within DU is straightforward (MME, CS, Knoebel, Phycology, NSM, Arts) and this will strengthen multidisciplinary activities.

When it comes to Unmanned Systems, competition is limited as only a handful of colleges / universities have established programs in this area. RSCES can make the top five list sooner than one may expect as on-going research has resulted in prototype systems – which makes DU different from the competition, and such lab prototypes may also be commercialized. Collaboration with other units within DU is also obvious as unmanned systems cover all aspects of science and engineering, also extending to legal and ethical challenges, public policy and international law challenges. The area of Unmanned Systems offers DU a unique opportunity to be the leader in Policy, Legal, Privacy issues, creating an umbrella institute under RSECS, Sturm, DCB and Corbel.

3. SMART CITY

Introduction

"The world has experienced unprecedented urban growth in recent decades. In 2008, for the first time, the world's population was evenly split between urban and rural areas, and it is expected that 70 percent of the world population will be urban by 2050."

- World Health Organization

Urban environments play a major role in modern economies as urbanization continuously brings new townships and more people are choosing to move to cities for a better quality of life. This significant shift demands a more intelligent and better planned use of available resources in urban environments, which has resulted in development of the concept of the Smart City. A Smart City is defined as a city that monitors and integrates conditions of all of its critical infrastructures for better optimizing its resources, planning its preventive maintenance activities, and monitoring security aspects, while maximizing services to its citizens (U.S. Office of Scientific and Technical Information).

The Ritchie School of Engineering and Computer Science holds a strategic position to lead the efforts in Smart City research and development. The core strength is in smart electricity grids, materials and structures, unmanned systems, and environment/climate. Smart City research has a cross-disciplinary nature, i.e., it goes beyond the limits of a department and school, is in line with National Academy of Engineering grand challenges and is aligned with National Science Foundation big ideas.

The significant strategic differentiators of Smart City research at RSECS are (1) the urban location, and (2) the current strength as well as potential collaboration with other departments within the university. This research area is strategically located to make connections across Denver and the Rocky Mountain region to many different active companies and organizations in this area. The possible collaboration with City and County of Denver, Xcel Energy, and National Renewable Energy Laboratory are some of the examples. Moreover, there is extensive ongoing research on urban communities in various departments within DU. Smart City research can be a host to bring together leading authorities from these departments to ensure state-of-the-art multidisciplinary research and education.

Smart City research supports faculty hiring and infrastructure development in areas complementing current expertise, specifically: smart grids, infrastructure management, computation and mathematics, and operations research. New faculty lines will allow building critical mass in the next five years to gain national reputation and to compete/join with other centers. Smart City market is predicted to be worth more than \$1.5 Trillion by 2020. The future of the Smart City research will include highly multidisciplinary teams that can tackle the current and emerging Smart City research and development problems from various perspectives while having citizens, as core players and enablers, in mind.

Overview

Urban environments play a major role in modern economies as urbanization continuously brings new townships and more people are choosing to move to cities for a better quality of life. According to the World Health Organization, for the first time in history the majority of the human population are city

dwellers. This significant shift demands a more intelligent and better planned use of available resources in urban environments, which has resulted in development of the concept of the Smart City. As defined by the U.S. Office of Scientific and Technical Information, a Smart City is a city that monitors and integrates conditions of all of its critical infrastructures for better optimizing its resources, planning its preventive maintenance activities, and monitoring security aspects, while maximizing services to its citizens. Critical infrastructures may include roads, bridges, tunnels, rails, subways, airports, seaports, electricity, communications, water, gas, and even major buildings.

Outstanding problems in climate will further provide opportunities to do important research over the coming decades. For example, climate sensitivity remains highly uncertain. Therefore, the calculation of the amount of carbon that can be safely burned remains uncertain and critical. IPCC reports that two of the largest sources of uncertainty in climate sensitivity concern the direct effects of aerosols and aerosol-cloud interaction. The DU Aerosol Group participated in 7 airborne studies of cloud-aerosol interactions from 2002 to 2013. We have been recently informed that Thomas and Reuters has identified a paper that we co-authored and that resulted from these studies as a Highly Cited Paper in Geosciences. This is a single example in a broader research area that will continue to attract interest and funding for the foreseeable future. These problems are becoming more pressing and they are not going to be solved out of existence any time soon.

Smart City market is predicted to be worth more than \$1.5 Trillion by 2020 (source: Strategic Opportunity Analysis of the Global Smart City Market – Frost and Sullivan). Figure 4 depicts the global Smart City market by segment. As the figure shows, the Smart City research is not bounded to one specific area, but it expands over several areas. Considering smart energy as one of the largest segments in this graph, and the current RSECS strengths, it would be natural to build the foundation on Smart Grids and further expand the research to other closely related areas under Smart City.

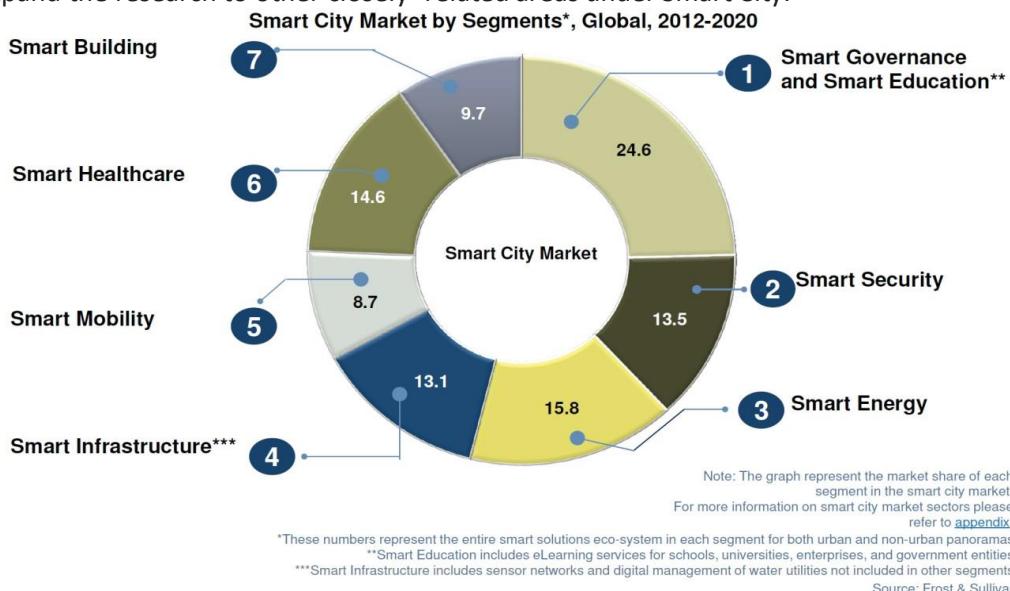


Figure 4: Smart City Market by Segment

Research and development in the area of Smart City is of growing interest and significance. Major factors contributing to invest in this strategic area are, but not limited to:

Smart City research has a cross-disciplinary nature: Key parameters that define a Smart City will include, smart energy, infrastructure, building, mobility, technology, healthcare, governance and education, security, and citizens. These key parameters clearly show the potential of this area to go beyond the limits of a department and school, and further necessitate cross-disciplinary collaborations. Smart City covers a wide range of topics, from smart energy, which has the ECE at its core, all the way to smart mobility which is at the intersection of several disciplines.

Smart City research is in line with NAE Grand Challenges: A focus on Smart City can potentially focus on two of the grand challenges identified by NAE: Make solar energy economical, and, Restore and improve urban infrastructure. The current solar produced global energy is less than 1% of the total energy production. However recent technological advances, combined with a growing interest of electricity consumers and incentive mechanisms by local governments, will make the case for higher deployment levels of solar energy. Our ongoing research on smart electricity grids provides the foundation for addressing this grand challenge. Better management of urban infrastructure also lies in the heart of Smart City research. Society is dealing with challenges of modernizing the aging infrastructure to provide better services to citizens while at the same meet economy and reliability targets. Our ongoing research on critical infrastructure management (both at ECE and MME) provides the groundwork for addressing this challenge.

Smart City research is federally supported: The White House made an initial investment of \$160 million last year on Smart City initiatives. This year an additional \$80 million is placed into Smart City projects (<http://www.govtech.com/fs/White-House-Puts-Additional-80M-Toward-Smart-Cities-Expands-MetroLab-Network.html>)

Smart City research is in line with NSF big ideas: An enabler of Smart City projects is the Internet of Things (IoT). IoT technology provides the required intelligence and flexibility to better manage resources. It is anticipated that city governments will considerably invest on IoT to upgrade their infrastructure. This huge IoT infrastructure will result in a wealth of data collected from multitude of heterogeneous measurement and control devices over the entire city. Accordingly data science would be required to analyze the collected data and to further convert to useful information and actions. This is in line with the NSF's big idea on "Harnessing Data for 21st Century Science and Engineering", while bridging research activities in ECE and CS.

Ongoing Research

Electricity infrastructure is one of the most critical infrastructures which is of utmost importance to our daily lives, is subject to ongoing radical changes, and plays a key role under Smart City framework. The electricity infrastructure for urban environments has been traditionally designed and operated with a heavy dependence on fossil-fuel, non-clean generation and with the assumptions of normal operation or limited component unavailability. This infrastructure, however, is neither environmentally friendly (as it lacks high penetration of emission-free generation resources) nor resilient against low probability high impact events (such as natural disasters or extreme weather events). Moreover, it lacks the fast and reliable monitoring system which enables a real-time control of available assets. Recent technological advances under the context of Smart Grid are being integrated into the electricity infrastructure for paving the road towards more intelligent electricity systems which can be efficiently used to achieve overarching goals of Smart Cities. These technologies include advanced metering infrastructure, renewable energy integration, transportation electrification, affordable energy storage, and distribution automation, to

name a few.

RSECS currently has research strengths in Smart Grid area. The faculty (A. Khodaei, W . Gao, and J. Zhang) has secured more than \$1.5 million since 2013, mainly from NSF, DOE, and DOE- affiliated laboratories. More than 20 PhD students are currently working in this area. Smart Grid research provides the foundation for research in Smart City. Dr. M. Kumosa's research on High Voltage/High Temperature Materials and Structures, with extensive industry funding, may also be part of Smart City. Dr. K. Valavanis' research on unmanned systems is an additional contributor to solve many of the monitoring/assessment problems in Smart Cities in response to component failures (as it is currently being adopted by many electric utilities).

Research on atmospheric science/climate in RSECS is led and coordinated by Dr. J. Wilson. Previous and ongoing research has provided sustainable funding (continuous since 1980), more than \$8M since 1993, to researchers in the DU Aerosol Group. Scholars in this area may contribute to DU's ability to broadly address climate change. While a large number of DU faculty are pursuing topics in sustainability, only a few are involved in physical science or engineering topics.

Hire Faculty in Key Areas of Collaboration – Total of Five (5)

It is proposed to hire 1 faculty member per year in Smart City over the next five years, to complement existing faculty expertise and capabilities. New faculty lines will allow for: (a) start building critical mass in the next five years to gain national reputation and compete with other centers; (b) flexibility to determine the best candidates for competitive faculty positions based on major research directions; (c) ensure that 1-2 new courses are added each year in this research area to be competitive not only in terms of research, but also in offering unique high quality educational service (to students as well as industry). The search will center on candidates with a strong background on the following topics: Smart grids – which is a current main area of research, but requires expansion; Infrastructure management – to provide a competitive edge in addressing problems in smart grid infrastructure management; Computation and mathematics – ongoing research is mainly computation based, so a faculty with this specific expertise is needed. It is also proposed to hire one endowed professor in this area (as part of the total of five new faculty). We do need one senior faculty who can help internally (by contributing to research activities) and externally (increase visibility and make the area known to the professional society). The home department for the new faculty could be either ECE or MME.

Financial Justification: Recent hires in the area of smart grid have shown that faculty can have a return as much as four times of the initial investment. The growing interest and considerable investment in Smart Cities and the potential funding opportunities are factors that can justify new hires from a financial perspective. It is reasonable to expect that new junior level hires will increase research volume by \$150K per year per new hire. The starting salary and startup will follow the standard rates (see above, Robotics).

Equipment/Space: As the research is mainly modeling and computation based, no major space will be needed. Equipment – wise, it will be of major importance to build a computer-based grid / city for performance evaluation. New / modern SCADA systems will also be needed. However research lab space will be required for new graduate students (mostly PhDs) added to the center.

Teaching Considerations: New hires will teach existing courses or offer new cross-disciplinary courses. Teaching load for new hires will be 1 course per quarter for the probation period.

Competitors and Collaborators

A major initiative in Smart City is the MetroLab Network. This network includes 38 cities, 4 counties, and 51 universities, organized in more than 35 regional city-university partnerships. The focus of

the partnerships is on research, development, and deployment projects associated with smart cities, including: inequality in income, health, mobility, security and opportunity; aging infrastructure; and environmental sustainability and resiliency. From the partnered universities, University of North Carolina-Charlotte could be a good model for comparison as the scope of its research is on smart grid, and they have a smart grid research project currently underway. UC- Boulder is partnered with Denver/Boulder, however another university joining in on one of these partnerships is a possibility.

The DU Aerosol Group collaborates closely with research groups at NCAR (National Center for Atmospheric Research), the NOAA Boulder Labs, the CU Department of Atmospheric and Oceanic Sciences (the DU Aerosol Group provided colleagues at NOAA with an inlet design, aerosol data and loaned equipment for the highly-cited paper). These collaborations have resulted in proposals, funding, collaborative research and papers. CSU's Atmospheric Science department offers additional opportunities for collaboration. The Aerosol Group also has a pending proposal written with a group at NASA Langley Research Center. NASA research groups have provided additional, but more distant collaborations with the DU Aerosol Group.

4. SECURING THE NATION'S CYBER FUTURE - CPS

Introduction

The internet is an essential tool for communication, commerce, and monitoring, with individuals, businesses, and governments relying on safe and reliable access to a broad array of services, including things like civil infrastructure maintenance, population health monitoring, and business process execution. However, the very connectivity that enables these innovative applications also exposes them to tampering and misuse. Thus, there is critical need for cyber-security for these systems to ensure reliable and safe access to data.

The University of Denver is invested in research in cyber-security for cyber-physical systems with initiatives in health care, internet-connected devices, and operational security. It has a small set of internationally acclaimed researchers in security and privacy, and growing programs in the area with the Colorado Research Institute for Security and Privacy (CRISP) and a new 1-year MSc program. Continued growth in this area is essential to ensuring the safety of our critical systems and their data.

Overview

An internet-scale system spans multiple networks and is composed of nodes with heterogeneous hardware and software characteristics. The ease of establishing connectivity between devices has now made it possible to design large scale networked systems with minimal effort, transport data between networks at real-time speeds, and develop innovative solutions that can leverage this distributed data-driven environment. Many services such as civil infrastructure maintenance, population health monitoring, business process execution, and consumer product customization are beginning to rely on the proper functioning of these internet-scale systems. However, the very connectivity that enables these innovative applications also exposes them, and, therefore, several critical infrastructures, to tampering and misuse (Figure 5). Needless to say, security and privacy are unavoidable dimensions in these emerging systems. New cyber security and privacy research opportunities are arising as large-scale personal data integration demands are identified, billions of cost effective devices are networked, and automated

processes cater to critical business, civil and military needs, to list a few.

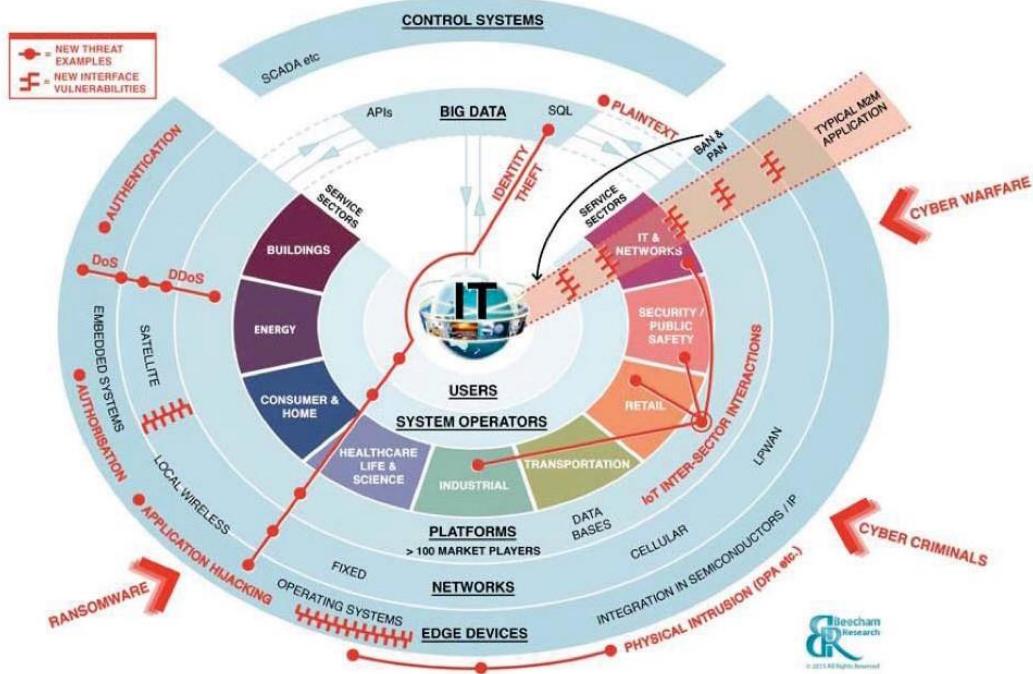


Figure 5: Security Threats in an Evolving Cyber Ecosystem.

Further, Cybersecurity investment is a global phenomenon, with an estimated \$655 million to be spent in initiatives to protect PCs, mobile devices and Internet of Things (IoT) devices between 2015 and 2020 (Figure 6). As such, cybersecurity research and development has received continued support from multiple federal funding agencies in the past, including the NSF, NIH, NIST, AFOSR and DoD. The market outlook on the aforementioned opportunities follows this trend. According to Market Research Media (<https://www.marketresearchmedia.com/?p=206>), "the U.S. Federal cybersecurity market size is estimated to grow from \$18 billion in 2017 to \$22 billion by 2022, at a steady Compound Annual Growth Rate (CAGR) of 4.4%." This claim is corroborated by recent announcements of investment plans coming out of multiple federal granting agencies.

The National Institute of Health is pushing for the development of "new strategies to analyze and leverage the explosion of increasingly complex biomedical data sets," which is projected to constitute a total investment of nearly \$656 million through 2020 (<https://www.nih.gov/news-events/news-releases/nih-invests-almost-32-million-increase-utility-biomedical-research-data>). NIH's Big Data to Knowledge (BD2K) initiative will "support the development of new approaches, software, tools, and training programs to improve access to these data and the ability to make new discoveries using them." Investigators will explore novel analytics to mine large amounts of data, while protecting privacy, for eventual application to improving human health.

The 2016 Federal Cybersecurity Research and Development Strategic Plan "challenges the cybersecurity R&D community to provide methods and tools for deterring, protecting, detecting, and adapting to malicious cyber activities." (<https://www.whitehouse.gov/blog/2016/02/08/national-challenges-and-goals-cybersecurity-science-and-technology>). The President's Fiscal Year 2017 budget

proposes a 35% increase (to roughly \$19 billion) in overall Federal resources for cybersecurity. As stated in the Federal Strategic Plan, "whether in government, academia, or the private sector, organizations that sponsor research, perform research, or advise on such investments have an opportunity to contribute." Along similar lines, IoT research initiatives will be able to procure funds from a diverse pool: over \$100 million in new grants by the NSF, NIST, DHS, DoT, DoE, DoC and the EPA, and over \$55 million in infrastructure development and unlocking new solutions (<https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-smart-cities-initiative-help>). All of these plans are starting to be executed as can be seen by an increasing number of research solicitations from federal agencies. A few of them include: NIH BD2K, NSF Smart and Connected Health, NSF SBIR/STTR: IoT, NSF Cyber-Physical Systems, NSF CyberCorps (R) Scholarship for Service, DoD Healthcare Management System Modernization, NSF Secure and Trustworthy Cyberspace, NSF Computer and Network Systems, along with annually released Broad Agency Announcements and solicitations from all major funding agencies.

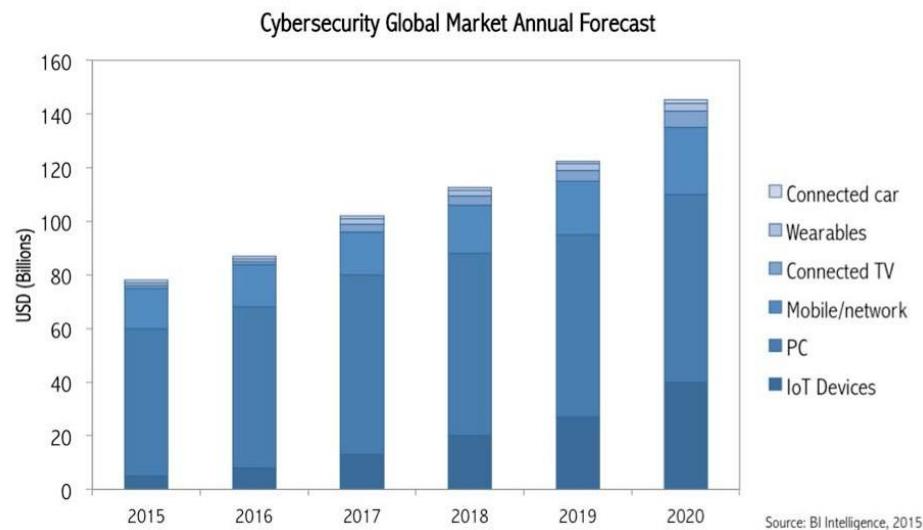


Figure 6: BI Intelligence estimates \$655 billion will be spent on cybersecurity initiatives between 2015 and 2020.

Opportunity

While issues related to security and privacy will likely touch upon multiple research activities in RSECS, three opportunities are highlighted wherein cyber security research will play a vital role in shaping the future landscape surrounding the realization of some impactful systems.

- *Health Data Informatics:* Health care is one of the largest segments in the U.S. economy, albeit one that is much behind in adopting digital information technology. It is well known that there is currently a significant push to transition to electronic health records and improve the exchange of health information in the US. Benefits from doing so are multifaceted: flexible access to health information, interoperability across health providers, cost reduction, and providing research data to inform clinical care, public health, and biomedical research, among others. However, a significant challenge lies ahead: multiple proprietary sub-systems have taken deep roots in the

current healthcare system, each using ad-hoc data formats and standards, and designed without interoperability or external access requirements in mind. Besides, health data is now available at dispersed locations: traditional sources such as disease registries, clinical and claims databases, electronic medical records, cohort and case control studies, and non-traditional sources such as social media, mobile and wearable devices, social and economic trends databases, and environmental databases. Technical solutions to integrate the different data repositories within an institution (or a select few) are underway, but large-scale integration across traditional and non-traditional sources remains a challenge owing to privacy regulations. Solutions have to employ strong cryptographic foundations in order to avoid the leakage of patient identifiers, a task that can be painfully slow when integrating millions of records. In addition, no software architecture currently exists to facilitate identity, authentication and privacy services across the multiply layers (UI apps, middleware apps, semantic translations, and search functionality) of a health information exchange system.

- *Internet of Things:* The Internet of Things (IoT) can be viewed as a massive network of sensor devices, computing nodes and mechanical machines, all with some form of connectivity within themselves and the Internet, and with the objective of carrying out conventional activities carried out by humans, or innovative tasks that were not possible earlier. Identified application areas include building automation, patient monitoring, industrial processes, retail and logistics maintenance, public safety, and smart agriculture, to name a few. IoT sensors may be embedded deep in a physical environment, thereby motivating cost effective and maintenance free designs. The evolution of IoT has therefore taken a direction where security considerations are treated secondarily. Although recent cyber-attacks (e.g. replay, false injection, and reverse engineering) on IoT systems have demonstrated the severity of outcomes due to such designs, a cost-effective security enforcement framework is yet to be seen for IoT. IoT systems are heavily context-based and cross-device interactions are open to imagination; traditional context-free security models based on firewalls and intrusion detection systems will not work. Billions of devices will have to coexist in the IoT, potentially with vulnerabilities that cannot be patched or is not cost-effective to patch.
- *Cyber Mission Assurance:* A cyber mission describes a cyber physical system's overarching goals. At an operational level, the mission involves complex dependencies between system activities, user activities, and resource usage defined by a workflow. A mission's requirements evolve over time, often necessitating changes to the infrastructure, activities, and their dependencies. Continuity of the mission is a more important goal than protecting the infrastructure on which it executes. Therefore, a mission being more than just network, infrastructure and physical devices on which it is executing, strategies for protecting a mission need to be identified and evaluated differently from those of protecting a cyber infrastructure. Mission resiliency must be evaluated following inter-dependent assessments on component dependencies, effects of cyber-attacks on the mission, hardening recommendations in near real-time, impact of user behavior on identified dependencies, and alternate security strategies, among others. There is currently a lack of formal methodologies for quantitatively evaluating the security and resiliency of cyber missions based on an understanding of the consequences and probabilities of the mission entering undesirable states.

Ongoing Research in RSECS

The Computer Science (CS) department at RSECS, under the umbrella of the Colorado Research Institute for Security and Privacy (CRISP) has initiated projects along the lines of the proposed research directions. The CRISP research group comprising of CS faculty members Prof. Ramakrishna Thurimella (algorithms and security), Dr. Matthew Rutherford (systems), Dr. Chris GauthierDickey (networks) and Dr.

Rinku Dewri (security and privacy) have worked on projects related to secure routing and consistency models in peer-to-peer networks, reputation systems, large intrusion detection environments and mobile privacy in the past 10 years. In terms of ongoing work, we have two projects in health data privacy: exploring privacy breaching attacks in health data integration techniques that the medical community is leaning towards, and developing web platforms and scalable tools based on cryptographic primitives for patient record integration. This line of work has already seen some success; at the least, we have been able to demonstrate that the techniques pursued by the medical informatics community can be compromised with little effort. Our students are also working towards designing security enforcers that can provide a security layer in IoT systems involving low cost sensors and insecure communication channels. We are determining what attack vectors are present in some popular IoT systems, demonstrating vulnerabilities, and developing open source hardware/software designs for their secure operation. Our research on cyber mission assurance is just beginning, with a focus on developing languages to express missions as workflows, formal models to describe security and resiliency of a mission, mathematically evaluating how mission outcomes are affected by improper working of individual components, developing metrics to assess mission robustness, and developing algorithms to dynamically assess network state and enforce real time mitigators. This work is planned in collaboration with faculty at Colorado State University, and initial interest from the National Institute of Standards and Technology (NIST).

Infrastructure and Hiring

The CRISP lab currently has limited infrastructure to pursue some of the emerging research areas stated earlier. Although planning on progressively adding to the infrastructure, there is immediate need to put together a basic environment so that some of the preliminary research activities can be initiated. In order to prevent unwanted injection of malicious content into the larger University network, the cybersecurity research environment should be isolated, with limited and strictly managed flow of traffic to the outside network. It is estimated that a total sum of approximately \$37,000 is needed in this initial setup.

The CS department has only two faculty members dedicated strictly to security and privacy research. One of these members (Prof. Ramakrishna Thurimella) is in the later stages of his career. As such, it is recommended to hire 3 faculty members with a focus on network security, systems security, and/or private biomedical informatics over the next five years. The diversity of expertise in security and privacy that will be introduced in RSECS by these hires will not only allow us to venture into emerging computer science research directions, but also enable novel collaborations with other research efforts in RSECS where security/privacy plays a critical role.

Although limited in size, the CRISP research group has internationally acclaimed researchers in security and privacy, and has been instrumental in bringing worldwide visibility to DU. With over 40 research articles published in the past ten years, the group has helped advance the state-of-the-art in security/privacy knowledge and tools. The CS department is also offering its recently approved one-year Masters program in Cybersecurity, and seeks to be at the forefront of cybersecurity education in the area. It is imperative that this momentum is utilized to grow and expand the University's cybersecurity research and education footprint to a sizable volume in the next five years.

5. ARTIFICIAL INTELLIGENCE

Introduction

Fundamental research in Artificial Intelligence (AI) is driving the technologies that will change the world in the next decade and beyond. From self-driving cars to personal assistants, the potential uses for AI techniques are growing quickly. This has been recognized nationally, with federal strategic plans for AI recommending that funding be doubled over the next few years. The private sector is also embracing the potential of AI, with large AI research groups at companies such as Google, Facebook, Microsoft, and many others.

Yet, with the new ubiquity of AI, there is also a need to understand the limitations of AI and to avoid applying AI techniques in ways that jeopardize our country, or in ways that unfairly discriminates against underrepresented members of society. With ongoing research in AI and its applications, DU has a strategic opportunity to broaden this work and establish itself as a force for the public good in AI research. It can do this by building a research area with traditional research expertise that is also applied to the question of the future of AI and of the ethical and moral challenges of deploying AI systems. As the use of AI broadens in our society, such work will be crucial in ensuring that we can shape this future in a way that will be equitable to all.

Overview

Artificial Intelligence (AI) is broadly impacting on the lives of individuals in society. From personal assistants such as Siri and Cortana to the promise of self-driving cars, or from the recommender systems used in online sites such as Amazon or Netflix to computer-aided medical diagnosis, the impact of AI on society is only expected to grow. AI techniques are also used broadly for commercial applications such as logistics planning or for data analysis. But, the impact of AI goes far beyond the individuals or companies on our planet. AI is also fundamental for space exploration, with AI planning techniques playing a crucial role in scheduling science operations on space missions.

AI is a broad field with numerous subfields in deterministic and probabilistic reasoning, problem solving, knowledge representation, natural language processing, and machine learning. Machine Learning (ML) is currently one of the fastest-growing areas of AI. With the use of ML, the old "recipe-based" paradigm of programming computers is slowly changing, and the impacts of these paradigm shift are slowly but steadily affecting the ways in which we program and interact with computers. Work in ML, particularly in the use of deep learning, has found widespread applications to many problems, and is one of the hottest areas in computer science. ML is changing the state-of-the-art in speech and image recognition, but was the core new technique used in the game-playing program AlphaGo, the first Go program to beat a top grandmaster in Go.

Yet, alongside these positive impacts are fears of AI running amok. Elon Musk, Bill Gates, and Stephen Hawking are but three voices of concern about the future of AI, and what might happen if learning systems grow without control. While most researchers in the field are not worried about rogue AI systems, it would be irresponsible to ignore the potential misuse of AI systems.

In October 2016 the US White House released the report "Preparing for the Future of Artificial Intelligence"¹. This comprehensive report discusses the definition of AI, the applications of AI for the public good, as well many other aspects of the future of AI. Along with this they developed a strategic plan for AI

to coordinate AI research and development plans across the federal government. Clearly this field is important to the future of our country.

The market for Artificial Intelligence and Machine Learning is exceedingly strong. Figure 7 shows the projected worldwide growth in Artificial Intelligence over the next 10 years.

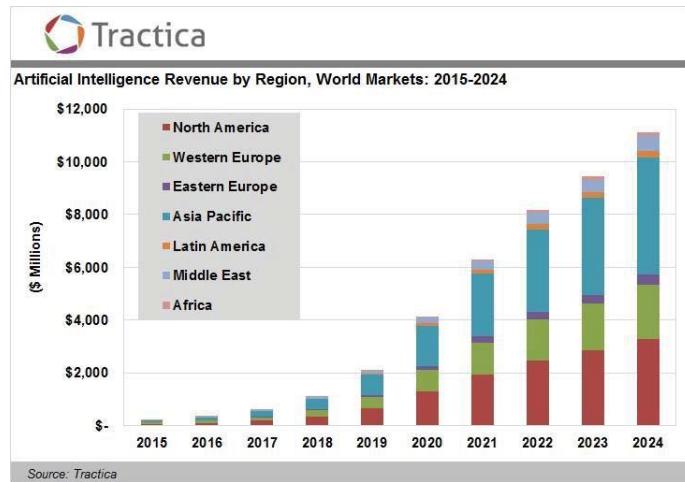


Figure 7: Projected growth in Artificial Intelligence revenue over the next 10 years.

While current revenue is under \$500 million a year, by 2024 revenue is predicted to reach over \$10 billion worldwide. This report includes areas of cognitive computing, deep learning, machine learning, predictive APIs, natural language processing, image recognition, and speech recognition. This doesn't include more traditional areas of AI including planning and reasoning. According Accenture, the market value of work in Artificial Intelligence as a whole is estimated to reach \$8.3 trillion in 2035 (<http://techemergence.com/valuing-the-artificial-intelligence-market-2016-and-beyond/>).

Ongoing Research in RSECS

Interest in AI crosses all three departments in RSECS. Primary research in AI is done by Dr. Nathan Sturtevant in Computer science in his Moving AI lab. This lab focuses on combinatorial search and optimization for problems such as path planning – how to move agents in virtual and simulated environments. Work in the lab also looks at large-scale search and multi-agent search. Dr. Sturtevant has collaborated with Dr. Rutherford and is currently collaborating with Dr. Lopez in CS on research projects in these areas.

Other faculty in RSECS are doing research that uses AI. For instance, Dr. Mahoor's group in ECE makes broad use of machine learning approaches such as support vector machines and deep learning. Dr. Lopez's research group is using machine learning for his work on music generation and in the development of personalized online learning systems. The MME faculty are extremely interested in applications of machine learning to problems in biomedical devices and technologies.

1 https://www.whitehouse.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/preparing_for_the_future_of_ai.pdf

Hiring

It is proposed to hire a faculty member each year over the next three years in AI. These hires would build a critical mass of artificial intelligence research. We are particularly looking for faculty that are making fundamental contributions to the field of AI in addition to applying their work to other fields. It is of particular interest to hire faculty that are interested in the application of AI for the public good, aligning with the broader DU strategic vision. Considerations for hiring include:

- Clear collaborations with faculty across RSECS. In this area the broadest need is in the area of machine learning. Machine learning is a broad field, with many subareas, so many that more than one faculty hire will be needed to establish a core distinguished area in machine learning.
- Faculty that can support broader initiatives of using AI for good. This aligns with the CS undergraduate games program which emphasizes humane gaming, and also aligns with interest in CS in improving education.
- Support of the proposed 1-year data science MSc. The data science MSc will involve courses in machine learning, data mining and statistics.

Financial Justification

The federal government expects to invest \$1.2 billion in AI research in 2016, but according to the October 2016 strategic plan, “doubling or tripling research investment would be a net positive for the Nation due to the resulting increase in economic growth”. They recognize that “AI qualifies as a high-leverage area, and research agencies report that the AI research community can absorb a significant funding increase productively, leading to faster progress on AI and a larger cadre of trained AI practitioners.” There is particular interest in “research with long time horizons conducted for the sole purpose of furthering the scientific knowledge base” because this is less likely to be funded by the private sector. Given this expected increase in federal funding, it is an opportune time to expand our strength in AI, as these investments will likely provide return in federal and commercial funding.

Competition

While there are large AI groups at many top universities (CMU, Georgia Tech, UT Austin, etc.) there is room to distinguish our work in AI by hiring faculty that are interested in the broader impacts of AI in society, and are willing to collaborate to do work in this area. This might include work on diversity and education, avoiding bias in AI systems that have a large societal control, or doing work to help understand how to make AI systems more human oriented in their decision-making process.

In addition to the above, RSECS has had success in atmospheric sciences because of one faculty member with international reputation: Dr. J. Wilson. This area, may continue to offer success to RSECS.