Concept Paper for Master of Science in Physics
(*offering research and professional options*)

Submitted by Dr. Michael Kotlarchyk, Professor and Head
School of Physics and Astronomy, College of Science

Goals and Justification for Proposed Program

The goal of the proposed program is to provide a graduate Physics degree that provides flexible options that can be tailored to the specific career goals and disciplinary interests of students seeking the Master of Science. The MS Physics program will offer students two overarching options. One option is research-focused and culminates in an MS thesis; the other option is designed to meet the criteria of a Professional Science Master's (PSM) program and to be recognized as being such in the PSM national registry [http://www.sciencemasters.com/]. Completion of the degree in either option prepares students to be highly employable across all sectors of the economy as well as for entry into PhD programs. Just as importantly, coursework offered by the program provides a sought-after general curricular presence and framework in physics that supports numerous other MS and PhD programs throughout RIT's portfolio of STEM graduate programs (particularly within the College of Science and the Kate Gleason College of Engineering). Courses offered through the program can also be used to seed the availability of an RIT graduate minor in Physics (in support of Objective II.4.2 in RIT's 2015-2025 Strategic Plan). Coursework in the program will provide requisite training in core areas of physics, both for students enrolled in this and other STEM graduate programs, as well as coursework in identified sub-areas of physics corresponding to three program disciplinary tracks offered to students enrolled in both the research and PSM options. The program contributes in an integral way to RIT's stated mission by delivering curricula and advancing scholarship and research relevant to emerging technologies and social conditions.

This program proposal is largely motivated by the available national data. According to the two latest (2014 and 2011) reports on *Physics & Astronomy Master's Initial Employment* [http://www.aip.org/statistics/reports/] from the ***American Institute of Physics (AIP) Statistical Research Center***, which together span the period 2006-2011, there were an annual average of about 800 exiting MS Physics graduates across the nation. That corresponds to about half of all MS Physics degree recipients if one includes those continuing en route towards earning their PhD. Approximately one-third of those exiting received their MS degree from non-PhD-granting departments, providing firm evidence that demand exists for a "terminal" MS program at RIT.

As substantiated by the AIP report, graduates of the proposed MS program in Physics will be highly employable across all economic sectors and in a wide variety of fields spanning the private sector, colleges and universities, high schools, and the government. The private sector, which employs about half of the physics MS degree recipients in the workforce, offers a very diverse set of STEM-related career options, with about two-thirds of these in various fields of engineering as well as in computer and information technology. During the period 2009-2011, the median salary for new holders of Physics master's degrees working in the private sector was $60,000. Graduates of our program will also find themselves well prepared and positioned to subsequently pursue a doctoral degree in physics or a related field should they desire to do so.

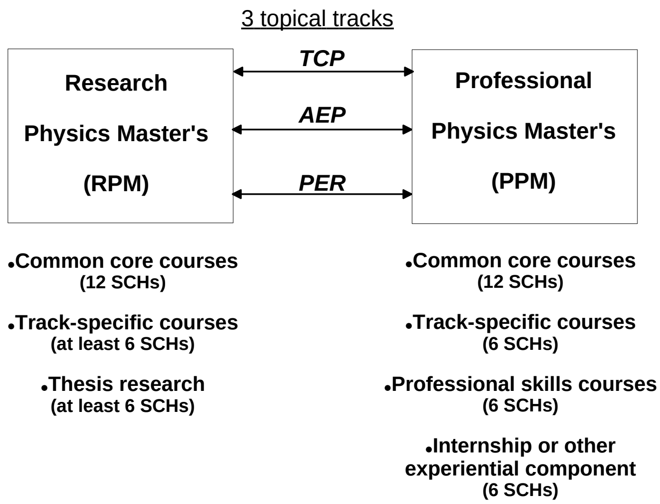
The data also points to the following four noteworthy facts: (1) About 30% of the employed physics master's graduates who were US citizens were continuing to work in positions that they accepted more than a year before receiving their MS degrees. This suggests a potential market for part-time students and/or for student's where an MS Physics degree might be encouraged, or even partially subsidized, by their employer. (2) About twice as many non-US exiting master's students went on to continue their graduate studies compared to the US exiting master's students. (3) Nearly one-quarter of exiting Physics master's degree recipients were women. This corresponds to approximately a 22% higher representation of women than one sees among PhD recipients in Physics. (4) The American Physical Society has developed a model for Physics Master's programs, such as the one we are proposing, to help bridge underrepresented student populations successfully into PhD programs [http://www.apsbridgeprogram.org/institutions/bridge/]. Our program would therefore likely have a positive impact on promoting diversity in Physics and the general graduate STEM population at RIT.

This program is also critically needed by the growing number of highly research-active faculty in the School of Physics and Astronomy in that it provides a pool of graduate students specifically trained in physics to support their expanding sponsored research efforts. Without these graduate students, faculty research efforts and the School's ability to attract external funding is compromised.

Once the MS program is approved, our intention is to promptly create a five-year BS/MS dual-degree connecting the bachelor's and master's physics programs. This will be mutually beneficial for recruiting and retaining physics students at both the undergraduate and graduate levels. More specifically, when prospective and early-year physics undergraduate students recognize that clear sub-disciplinary tracks are being seeded from above, i.e., those that facilitate desirable programmatic and career trajectories, they can actively aspire toward attractive options and career paths early on. This will further strengthen our already strong growth in the BS Physics Program that we have been experiencing over the last 15 years (the BS program had 41 majors in 2000, 73 majors in 2006, and 142 in 2014). Obviously, those students who formally enroll in the dual BS/MS degree will also positively impact the Physics enrollment numbers at the graduate level.

Description of the New Program

The proposed MS program will be organized into two primary options, namely, a *Research Physics Masters* (RPM) and a *Professional Physics Masters* (PPM) as illustrated below:



Both program options provide students with the same advanced core knowledge that crosses the discipline of physics, along with additional coursework in one of three topical tracks selected by the student. Initially, the three tracks offered will be:

- *Theoretical and Computational Physics* (**TCP**)
- *Applied and Experimental Physics* (**AEP**)
- *Physics Education and Research* (**PER**)

Courses will be delivered at a typical physics graduate level, hence entry into the program requires an undergraduate degree in Physics or a closely-related degree containing significant undergraduate physics coursework.

The RPM Option requires a research thesis, whereas the PPM Option requires two courses aimed at enhancing professional skills as well as an experiential component such as an internship. The skills courses and options for the experiential/internship component will be identified and developed in consultation with School of Physics & Astronomy advisory board members representing industry, business, government, and both K-12 and higher education. Preliminary conversations have recently taken place with the Saunders College of Business, and Interim Dean, Jacqueline Mozrall, has provided us with a statement expressing support for our PPM Option and for identifying suites of MS business courses that would be professionally beneficial to students in our program. We also envision availing students in the PPM Option with professional skills courses that enhance knowledge in science, technology, and public policy, as well as courses that elevate proficiency in written and oral communication skills.

The program requires that students earn a minimum of 30 credits in total, consisting of at least 18 course credits and at least 6 credits devoted to either thesis research or a professional experiential component, and is designed to be completed over a span of two years.

Here are more specifics on components of the program:

Common Core Courses: Students are required to complete the following four core courses:

- *Quantum Mechanics I* (new course currently being developed and piloted)
- *Statistical Physics I* (new course)
- *Classical Electrodynamics I* (course <u>already offered</u>, PHYS-611)
- *Mathematical Methods for the Physical Sciences* (<u>already offered</u> for the *Astrophysical Sciences*, i.e., ASTP-610, but is easily generalized to support Physics and Astrophysics)

These courses provide essential knowledge that underpins all three topical tracks within the program. The core courses are each offered once per year and are normally taken during the first year.

<u>Track-Specific Courses</u>: Students enrolled in both the RPM and PPM Options must take at least two graduate courses within their chosen track. Track-specific courses are made available at least every other year, and are either offered by the program or by other RIT STEM graduate programs that are approved for the particular track. The following new track courses (with the applicable track(s) shown in parentheses) will be developed by the School of Physics and Astronomy:

- Quantum *Mechanics II* (TCP, AEP, PER)
- *Statistical Physics II* (TCP, AEP, PER)
- *Topics in Soft-Matter and Biological Physics* (TCP, AEP)
- *Scattering and Spectroscopy as a Probe of Matter* (AEP)
- *Atomic-Scale and Other Microscopies* (AEP)
- *Teaching and Learning Physics* (PER)

The following track courses <u>already exist</u> at RIT at the graduate level. (Dean Harvey Palmer has relayed that he is supportive of Physics MS students using KGCOE graduate courses as track-specific courses):

- PHYS-612 *Classical Electrodynamics II* (TCP, AEP, PER)
- ASTP-760 *Introduction to Relativity and Gravitation* (TCP)
- ASTP-861 *Advanced Relativity and Gravitation* (TCP)
- IMGS-737 *Physical Optics* (TCP, AEP, PER)
- MCSE-702 *Introduction to Nanotechnology and Microsystems* (AEP)
- MCSE-713 *Lasers* (AEP)
- MCSE-712 *Nonlinear Optics* (TCP, AEP)
- MCSE-731 *Integrated Optical Devices and Systems* (AEP)
- MCSE-771 *Optoelectronics* (AEP)
- MCSE-889 *Quantum Optics* (TCP, AEP)
- MATH-711 *Advanced Methods in Scientific Computing* (TCP)
- MATH-712 *Numerical Methods for Partial Differential Equations* (TCP)
- MCEE-620 *Photovoltaic Science and Engineering* (AEP)
- EEEE-713 *Solid State Physics* (TCP, AEP)
- EEEE-620 *Design of Digital Systems* (AEP)
- EEEE-610 *Analog Electronics* (AEP)
- EEEE-689 *Fundamentals of MEMS* (AEP)
- *Neutrons in Soft-Matter Science: Complex Materials on Mesoscopic Scales* (AEP)—this is one of a number of novel *Cyber-Enabled Collaborative Graduate Education* courses that is offered by and streamed live from Oak Ridge National Lab [http://neutrons.ornl.gov/education/graduate/]

<u>Professional Skills Courses</u> (PPM Option <u>only</u>): During the second year, PPM students are required to take two graduate courses that will enhance skills relevant to the student's anticipated professional environment. These can be courses in such areas as organization and leadership, managing research teams, promoting innovation and technology, entrepreneurship and intellectual property, finance and accounting, teaching practice and pedagogy, science/technology/public-policy, and communications. The Saunders College of Business, the College of Liberal Arts, and the College of Science already offer a number of excellent courses in support of these goals.

Thesis Research (RPM Option only): In the second year (and/or during summer terms), RPM students undertake a research project within their chosen track under the guidance of a faculty member. Students must defend their thesis, and it is generally expected that they will aim to disseminate their thesis research in a peer-reviewed journal or conference proceeding.

Internship or Experiential Component (PPM Option only): In the second year (and/or during summer terms), PPM students undertake an internship or similar approved practicum experience in support of their desired career path. With guidance and assistance from an advisory board and the RIT Career Placement Office, we will identify and facilitate opportunities with industrial partners working in areas such as materials science, electronics and the semiconductor industry, optics and photonics, energy science, computer/information technology, and scientific computation/simulation. Excellent resources at the national level in support of industrial connections for the PPM Option are the American Physical Society's ***Forum on Industrial and Applied Physics*** [http://www.aps.org/units/fiap/] and the American Institute of Physics ***Corporate Associates Program*** [http://www.aip.org/ca]. In particular, the mission statement of the latter program states "*We create unique networking opportunities between leading industrial research executives and scientists at major academic institutions and government laboratories.*" We also anticipate that some PPM students will want to work toward becoming high school physics teachers, which is nationally the number one area of need for teaching in US secondary schools. We will develop attractive opportunities with regional colleges having schools of education such as St. John Fisher, Nazareth, and Ithaca College to provide students paths toward teacher certification.

Fit with RIT Academic Portfolio Blueprint

The fit of the proposed MS Program in Physics to the ***six Academic Portfolio Blueprint (APB) characteristics*** follow:

Scholarship, Research, and Creativity: All students enrolled in the RPM Option, under the guidance of a research-active faculty member, are required to perform an original thesis research project with the goal of disseminating the work in a peer-reviewed journal or conference proceeding. Such research dissemination will strengthen the ability of faculty to attract external sponsored research funding, which in turn will increase the number and quality of research projects made available to students by the faculty.

Innovative Teaching and Learning: The curriculum will make use of technological resources. This includes having an electronic presence for all program courses, embedding computation and simulation components as part of pedagogy, and employing technology that is germane to track-specific courses containing a lab or practical component, as appropriate. Alternative distance delivery opportunities, for example, via *Adobe Connect*, offered by the professional physics community (such as the Oak Ridge *Cyber-Enabled Graduate Education* course listed in the previous section) will be encouraged as a way for students to partially fulfill track-specific course requirements, and at little or no cost to the program. Also, having our program faculty become directly involved in the delivery of these courses presents an excellent opportunity for extending the reach and influence of our program and RIT to venues beyond the campus.

Experiential Learning: The thesis research requirement fulfills the experiential learning expectation for students in the RPM Option, and the internship or similar experience fulfills this expectation for students in the PPM Option of the program. All thesis projects are applied to real-world problems relevant to the physical world and the betterment of society, and all internships directly support developing the student's practical skills and experience relevant to success in the workforce.

International and Global Education: The discipline of physics, historically and by its nature, is an international enterprise involving numerous collaborations between and among academicians, government agencies and industrial partners, including the long-term planning and sharing of state-of-the-art facilities, around the globe. The faculty and students in the MS Physics Program will unavoidably participate in these conversations and will continue to engage with international collaborators. The aforementioned alternative distance delivery opportunities for program faculty with national labs and other entities will inherently bring about connections with the international scientific community. A memorandum of understanding is currently being arranged between RIT and Universidade Federal Do Rio Grande Do Sol (UFRGS) in Brazil to forge research and educational connections between the RIT School of Physics and Astronomy and the UFRGS Institute of Physics—our proposed MS program will no doubt benefit this initiative. Similar articulated agreements between other potential international partners such as France, India, Japan, and Sweden are currently being actively pursued by the School.

Synergy and Interdisciplinarity: Because physics provides the underpinnings of all natural and applied sciences, as well as engineering, it crosses all STEM disciplines. Specific interdisciplinary synergies between the proposed program and other academic units and research centers in both COS and across the campus are described in the section on "Synergy with Other Programs" that follows. Courses offered through the program can also easily be used to create an RIT graduate minor in Physics

Inclusive Excellence: As emphasized previously, based on national data collected by the American Institute of Physics which shows that nearly one-quarter of Physics master's recipients are women, we expect that the proposed MS Program in Physics will positively impact attracting women students to Physics and the general graduate STEM population at RIT—and more so than would a physics Ph.D. program. COS's Women in Science program will contribute to career mentoring, networking opportunities, and general support for female students in the program. Graduate students in the program can also act as effective role models and mentors for STEM undergraduates from underrepresented populations engaged in physics research in our school, for example, those supported by the RIT McNair Scholars Program. An added goal of the Physics MS Program is to act as an effective academic bridge for underrepresented minority students. This goal connects to a recent initiative by the American Physical Society promoting such bridge programs that provide minority students with graduate coursework and academic mentoring that would help them thrive and gain entry into PhD programs [http://www.apsbridgeprogram.org/institutions/bridge/].

Here are some of the program features contributing to the fit of the Program to the ***four APB criteria***:

Centrality: The program will enhance RIT's overall reputation by contributing in a significant way to RIT's stated mission aimed at developing and delivering curricula and engaging in scholarship and research that plays a role in advancing emerging technologies and improving conditions within society. This is true even beyond the confines of the proposed program in that a portfolio of graduate-level physics courses being requested by a number of STEM programs and students around the campus will become available. There is an increasing demand at RIT for more advanced courses in physics and, in some cases, these turn out to be an essential component for the graduate education of students in certain programs (for example, Microsystems Engineering, Astrophysical Sciences & Technology, and Imaging Science). Just as importantly, the projects associated with the research component of the program almost always tend to be interdisciplinary in character, producing natural and lasting collaborations with faculty colleagues in almost every college at RIT.

Marketability: Based on available national and regional data, RIT's Office of Enrollment Management and Career Services projects that the program will realistically be able to reach and sustain a steady-state enrollment of 20-25 students, with about half of this population entering internally through a BS/MS Physics dual-degree program. As mentioned earlier, national data indicates that the program may also attract some part-time enrollment in the program. An MS Program in Physics also elevates the marketability of other RIT STEM graduate programs. An example, although anecdotal, was relayed by a very strong woman applicant who respectfully declined admission to the Astrophysical Sciences & Technology PhD Program: "*…in order to succeed in research and academia, I feel that I will need the opportunity to strengthen my physics base knowledge through graduate level physics courses.*" Program marketability information is provided in the included section on *Enrollment Management Expectations and Sustainment*.

Quality: The quality of this program largely hinges on the qualifications of our faculty to offer it. All of the current 22 tenure-track physics program faculty, as well as the 15 non-tenure-track faculty, in the School of Physics and Astronomy have a Ph.D. degree in Physics or a closely related field. A large fraction of the current faculty have recent experience supporting and supervising graduate students in other RIT STEM programs including Astrophysical Sciences & Technology, Materials Science & Engineering, Chemistry, Applied Mathematics, Microsystems Engineering, Electrical Engineering, Imaging Science, Computer Science, and Sustainability. Additionally, a majority of the faculty have acted as research mentors in support of the individualized senior capstone research projects required for all students in the BS Physics Program. In a typical recent year, the RIT physics faculty publish 60-80 peer-reviewed papers and attract about $2-3M in external sponsored research funding. The School feels well positioned to launch the Physics MS Program.

Financial Viability: The program will efficiently make use of existing physical, financial, and faculty resources currently available within the School, including many courses that already exist in COS and KGCOE. Resource needs primarily associated with incremental faculty are detailed in the included cost model analysis, and are based on the projected enrollment plan.

Synergy with Other Programs

The program integrates naturally and substantially with numerous disciplines, other programs, and other colleges at RIT. Students will benefit from numerous graduate course options offered by KGCOE and COS, as shown in the *Description of the Program* section. Quoting an email from Harvey Palmer, Dean of KGCOE, "*I am definitely supportive of the proposal.*" On the flip side, even in the absence of a Physics graduate physics program at present, beginning in 2013-14 the School of Physics & Astronomy began offering a two-semester graduate sequence to support students enrolled in existing science and engineering programs on campus, i.e., *Classical Electrodynamics I & II*, which is one of the main course sequences in the Physics MS Program. This sequence was put in place primarily to satisfy the new course requirements for one of the tracks in the Astrophysical Sciences & *Technology* (AST) program. Unexpectedly, in addition to the 5 AST (4 PhD, 1 MS) students, there were also 2 Microelectronic Engineering (MS) students, 1 Imaging Science (PhD) student, and 1 Microsystems Engineering (PhD) student enrolled; 1 upper-level undergraduate Physics student also regularly sat in on the classes. The demand for the first-time offering of this sequence was significantly higher than expected, and the instructor relays that the performance-level of the students in this advanced class was very impressive. In addition, due to recent student demand by STEM graduate students, we are also delivering a *Quantum Mechanics* Special Topics course during the current 2014-15 academic year (even though such a course is not currently a requirement for any RIT program).

Courses offered by the program in the area of Physics Education Research will undoubtedly be attractive to any students interested in STEM education. These courses could easily be delivered in a dual-level fashion for both undergraduate and graduate students, making these courses sustainable and cost effective. The proposed course in *Teaching and Learning Physics*, for example, would clearly support students participating in the rapidly growing *Learning Assistant* (LA) program evolving within COS and the RIT-Nazareth *Tech2Teach Program* that facilitates a pathway for STEM students considering a career in secondary education [http://www.rit.edu/cos/tech2teach].

All in all, clear synergies abound between the proposed program and other graduate programs and research centers at RIT, with the closest overlaps with the following:

Academic Programs	Research Centers, Labs, & Clusters
Astrophysical Science & Technology (PhD, MS)	Center for Computational Relativity & Gravitation
Imaging Science (PhD, MS)	Nanopower Research Laboratory
Microsystems Engineering (PhD)	Center for Applied & Computational Mathematics
Sustainability (PhD)	Center for Detectors
Engineering (PhD)	Laboratory for Multiwavelength Astrophysics
Applied & Computational Mathematics (MS)	Semiconductor/Microsystems Fabrication Laboratory
Microelectronic Engineering (MS)	Center for Advancing Science and Mathematics Teaching, Learning, and Evaluation
Material Science & Engineering (MS)	
Physics (BS)	
Mathematical Modeling &Scientific Computing (PhD proposal)	

Administrative Structure for the New Program

The MS Program in Physics will be administered by COS's School of Physics and Astronomy, which currently houses the Physics BS Program, as well as the Astrophysical Sciences & Technology PhD and MS Programs. A Director for the MS Physics Program will report to the Head of the School, and will coordinate the program's operation and student recruitment.

Enrollment Management Expectations and Sustainment

Dr. James Miller, Senior Vice-President for Enrollment Management & Career Services, and Diane Ellison, Assistant Vice-President in Graduate Enrollment Services, reviewed the proposed program. Here is the direct response to Dr. Mike Kotlarchyk (Head, School of Physics & Astronomy) from Diane Ellison on February 19, 2015 concluding that a steady-state enrollment of 22 students in the program each year is a realistic projection, with about half of the students coming from new external candidates and about half coming through the BS/MS Physics Program:

Mike: We provide this input based on the program model offering three tracks containing three common courses, two of which are new, and six additional courses to support the tracks. The target population is full-time from within and outside RIT. The outside market is competitive and will require various competitive funding models for students be in place.
The following information assumes a BS/MS and MS both commencing simultaneously in fall 2016 (or 2017, depending on program approval timeline). *This scenario assumes NYS approval is forthcoming in summer 2015 to allow a full marketing cycle. If NYS approval is not forthcoming until 2016, then the start should simply be moved from 2016 to 2017.*
Given desired quality thresholds, we believe it is realistic to project 6-7 new external MS candidates and 5-7 BS/MS candidates. Overall, I estimate 10 new in the first year, with 12-13 new in each subsequent year.
For purposes of planning I suggest using the following FTE figures: Year 1, 10; Year 2, 20; Year 3, 22; year 4 and beyond, 22. For this scenario a 35% discount rate should be used for year 1. For year 2 and beyond use a 27-30% discount rate.
Note that any BS/MS enrollees are considered new graduate enrollees at the point they are classified level 6 in RIT's student records system. This distinction is important for assessing the overall financial viability of your proposal. Please let me know if you need any additional information at this point—Diane

We intend to start the program for both the MS and the BS/MS students in fall 2017. Per the above email, a 35% tuition discount rate would be applied in Year 1 of the program and a 27-30% discount rate would be applied in Year 2 and beyond. Partial financial support will be available in the form of teaching assistantships funded by the School and some students will receive full stipend funding and/or summer support from faculty-sponsored research grants.

Impact on Resources

The base resources to support the MS Program in Physics will primarily come from the existing space and facilities currently available within the School of Physics & Astronomy (SoPA) and the College of Science, as well as from other existing academic and research infrastructure alliances and cost-sharing arrangements currently in place with other colleges, laboratories, and centers around campus. However, in steady state, to annually offer the 2 new core courses, to offer a sufficient number of courses to support the three proposed topical tracks (where School faculty teach at least 4 of such courses each year), and to supervise the MS thesis projects for students enrolled in the RPM Option each year, there will be the need for 2 FTE additional tenure-track faculty (and associated office space). Basic-level start-up packages are being requested for the two new faculty, but we do not anticipate requesting incremental lab space to support their research efforts. Rather, the two new faculty will be incorporated into existing research centers and laboratories or will be hired in support of computational, theoretical, or pedagogical research areas. There will be a need for some desk space for the grad students we would be unable to accommodate in research laboratories. Teaching release of one course per year is requested for the faculty member taking on the role of MS Program Director. Administrative staff assistance will be provided by existing personnel in the School.

The required cost model analysis template accompanies this concept-paper submission.

Conclusion

The MS Program in Physics will complement and be integral to supporting the existing and developing portfolio of STEM graduate programs in science and engineering across RIT. The structure of the degree program allows students to select either a research-based option or a professionally-focused option. Both options will produce graduates having marketable training and skills known to be desirable in all sectors of the economy spanning a wide variety of STEM fields. The program will also provide very strong preparation to those who decide to continue on for PhD-level training in Physics and related fields. We expect that the existence of the three topical tracks at the graduate level will have the significant additional benefit of boosting retention in and strengthening recruitment and program marketability aimed toward our undergraduate population of physics students. This will be enhanced by putting in place a BS/MS dual degree program in Physics. The MS program will add further vitality to the overall research enterprise at RIT by elevating collaborations that cross disciplines and programs. Additionally, the mere presence of a graduate program in Physics and the availability of physics graduate students in support of research will have a positive impact on the success rate for faculty submitting proposals for sponsored projects.

MS in Physics
SUMMARY REPORT

Fiscal Year	2018	2019	2020	2021	2022	Total
Avg Enrollment: Students (FT + PT)	10	20	22	22	22	97
Part-time Faculty expense	$ -	$ -	$ -	$ -	$ -	$ -
Full-time faculty expense	$ 123,534.94	$ 252,011.29	$ 257,051.51	$ 262,192.54	$ 267,436.39	$ 1,162,226.68
Total Expenses	$ 269,629.13	$ 418,112.21	$ 392,104.99	$ 399,902.09	$ 407,855.13	$ 1,887,603.56
Revenue (Net of Aid)	$ 241,279.18	$ 431,190.03	$ 488,325.21	$ 478,675.87	$ 488,325.21	$ 2,127,795.50
CONTRIBUTION MARGIN Surplus/(Deficit)	$ (28,349.94)	$ 13,077.82	$ 96,220.21	$ 78,773.78	$ 80,470.07	**$ 240,191.93**

Note : This sheet is password protected to maintain the formulas.