Program Review
2020-21

Bachelor of Science in Physics
Colorado Mesa University

Prepared by

The Physics Faculty

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1. Introduction and Program Overview

a. Program Description

The Physics Program at Colorado Mesa University is part of the Department of Physical Environmental Sciences, along with the Chemistry, Geology, and the Environmental Science programs. These programs share a department head, but are individually managed by program coordinators as an independent unit to control its curriculum, schedule classes, and set program priorities. Each program has its own faculty, labs, and budget.

The Physics Program is dedicated to quality undergraduate education and research opportunities. Class sizes in upper-level courses remain small, and all physics majors complete at least one year of research under close supervision of one of the physics faculty.

The Physics Program offers a Bachelor of Science (B.S.) degree in Physics, an Associate of Science (A.S.) in Liberal Arts with an emphasis in Physics, and a Minor in Physics.

b. Brief History of the Program

Prior to 1993, physics was an area of emphasis along with computer science, geology, and mathematics under the Bachelor of Science in Physical and Mathematics Sciences. In 1994, the Bachelor of Science in Physical Sciences was introduced, which initially included concentrations in geology and physics, with chemistry being added as a concentration in 1995. A concentration in Applied Physics was added 1997, but was later removed in 2004. This concentration framework was in place until 2013, when the concentrations were removed and a Bachelor of Science in Physics was introduced. While the Physics Program has continually evolved in the past 30 years, the change from physics being a concentration to a distinct major did not introduce any major changes to the curriculum. The Physics Program currently (Fall 2021) includes five tenured/tenure-track faculty, one full-time visiting assistant professor, and one full-time instructor. In most semesters, one to three additional adjunct faculty are hired to teach additional first-year laboratories.

c. Recommendations from the Academic Year (AY) 2012-13 PES Review

<u>Recommendations made by Department of Physical and Environmental Sciences in the Review:</u>

Significant growth of introductory "service" courses requires additional full-time faculty.

> *Response: The number of full-time faculty has increased from five to seven since AY 2012-13.*

Some of our classes are held in classrooms outside of Wubben Hall and Science Center, which somewhat limits physics demonstrations that are beneficial to student learning.

Response: Some classes are still held outside of Wubben Hall. Due to space limitations in Wubben Hall, the Physics Program does not have complete control in selecting classrooms within Wubben Hall for all courses.

<u>Recommendations made by External Reviewer – Highest Priority:</u>

Recommendation 1: All programs can justify additional tenure-track faculty positions.

Response: The number of tenured/tenure-track faculty has increased from four to five whereas the number of full-time faculty has increased from five to seven.

Recommendation 2: Develop and execute an Assessment Plan for each program (concentration or "major").

Response: The Physics Program developed an Assessment Plan in AY 2013-14. We recently completed our six-year Assessment Plan review.

Recommendation 3: Seek final approval for discrete chemistry, geology, and physics designated major programs.

Response: The Department of Physical and Environmental Sciences now offers a distinct Bachelor of Science degree in Physics.

Recommendation 4: Identify strategies to convert students identified as program majors to graduates (particularly chemistry).

Response: While not directly applicable to physics, the Physics Program maintains close communication with physics majors through small class sizes and the Society of Physics Students (SPS) club.

Recommendation 5: Continue to explore additional program opportunities, particularly at the boundary of traditional disciplines, and which rely on existing resources in-so-far as possible.

Response: The physics faculty have regularly involved students in a broad range of research projects, beyond the scope of course curriculum, such as quantum information, general relativity, and computational physics.

Recommendation 6: As the future is contemplated, develop a firm, persuasive vision (or "sense of self") for the physical sciences' disciplines.

Response: With recent additional hires, the Physics Program is confident in its ability to offer a wide variety of strong research opportunities to all students completing a physics degree. The Physics Program has also developed a mission statement.

Recommendations made by External Reviewer – Other Recommendations:

Regarding faculty evaluation, broaden the physical sciences "definition" for the scholarly expectation.

> *Response: An ad-hoc committee was formed in AY 2019-20 to review the faculty evaluation guidelines for the Department of Physical and Environmental Sciences. As a result of this meeting, scholarly activities that fulfill this expectation have been detailed to better inform faculty of these expectations.*

Regarding CMU Catalog descriptions, review Catalog course descriptions for CHEM, GEOL, and PHYS to ensure accurate and informative copy.

> *Response: The catalog descriptions and course prerequisites have been modified and improved for many of our physics courses during this review period.*

Regarding laboratory-based instruction, such offerings to accompany lecture course counterparts seem to be at a minimum (perhaps based on staffing and space considerations).

> *Response: PHYS105/105L was specifically addressed in this comment. With changes to the preservice elementary education programs, this course did not fulfill that program's requirements and thus there was no demand to continue this course. Consequently, it was removed from the Physics Program course listings. However, we do see an opportunity for a physics lecture and lab combination for the Essential Learning Requirements, and are currently exploring the feasibility of an astronomy laboratory. The astronomy course has historically been a high-demand class, and an astronomy laboratory could see broad appeal to the students looking to fulfill this lecture and lab Essential Learning Requirement.*

Regarding preservice secondary teacher education, investigate the State of Colorado Guidelines for licensure for teaching middle and secondary school "science" subjects (inclusive of biology/life science, chemistry, earth science, and physics.

> *Response: The Center for Teacher Education at CMU currently offers several degrees for students pursuing teaching careers in the school science subjects. These degrees lead to appropriate licensing for the state of Colorado.*

d. Mission Statement and Goals

Colorado Mesa University serves the citizens of Colorado, with a specific emphasis on increasing the level of educational attainment of residents in its 14-county region in Western Colorado. Colorado Mesa University's mission, established by the Colorado Legislature, is contained in Colorado Revised Statutes (C.R.S) 23-53-101:

> *There is hereby established a university at Grand Junction, to be known as Colorado Mesa University, which shall be a general baccalaureate and graduate institution with*

selective admission standards. Colorado Mesa University shall offer liberal arts and sciences, professional and technical degree programs, and a limited number of graduate programs. Colorado Mesa University shall also maintain a community college role and mission, including career and technical education programs. Colorado Mesa University shall receive resident credit for two-year course offerings in its commission-approved service area. Colorado Mesa University shall also serve as a regional educational provider.

The CMU Board of Trustees has also established an Institutional Mission Statement:

> *Committed to a personal approach, Colorado Mesa University is a dynamic learning environment that offers abundant opportunities for students and the larger community to grow intellectually, professionally, and personally. By celebrating exceptional teaching, academic excellence, scholarly and creative activities, and by encouraging diversity, critical thinking, and social responsibility, CMU advances the common good of Colorado and beyond.*

The Physics Program has recently developed a program-level mission statement:

> *The Physics Program at Colorado Mesa University aims to equip students with the knowledge, skills, and abilities necessary for a career or graduate study in science, technology, engineering, and math (STEM). In addition to fluency with the major fields of physics, the program emphasizes quantitative and analytical reasoning, hands-on laboratory experience, written and oral communication, and high-quality physics research. The program strives to create a positive and individualized learning environment for students of all backgrounds via small classes paired with supervised projects that allow for an abundance of student-faculty interaction.*

Colorado Mesa University has established student learning outcomes for each degree level. The CMU baccalaureate degree graduate will be able to:

- Construct a summative project, paper, or practice-based performance that draws on current research, scholarship and/or techniques, and specialized knowledge in the discipline (specialized knowledge /applied learning).
- Analyze data critically, reason logically, and apply quantitative analysis methods correctly to develop appropriate conclusions (quantitative fluency).
- Make and defend assertions about a specialized topic in an extended well-organized document and an oral presentation that is appropriate to the discipline (communication fluency).
- Describe reasoned conclusions that articulate the implications and consequences for a particular decision by synthesized information and methodologies (critical thinking).
- Reflect on and respond to ethical, social, civic, and/or environmental challenges at local, national, and/or global levels (personal and social responsibility).
- Find relevant sources of information, evaluate information critically, and apply the information appropriately and effectively to specific purposes (information literacy).

In addition to these campus-wide student learning outcomes, a graduate with a physics major will be able to:

- Show fluency with the major fields of physics – classical mechanics, electromagnetism, statistical physics, and quantum theory (specialized knowledge).
- Use mathematical representations to analyze physical scenarios (quantitative fluency).
- Use laboratory techniques to investigate experimentally physical phenomena (applied learning).
- Communicate effectively about topics in physics (communication fluency).
- Execute a project which addresses a significant and complex issue in physics. This project will integrate knowledge and techniques from different areas of physics (specialized knowledge /applied learning).

The CMU associate degree graduate will be able to:

- Locate, gather, and organize evidence on an assigned topic addressing a course or discipline-related question or a question of practice in a work or community setting (specialized knowledge / applied learning).
- Use program-level mathematical concepts and methods to understand, analyze, and explain issues in quantitative terms (quantitative fluency).
- Make and defend claims in a well-organized, professional document, and/or oral presentation that is appropriate for a specific audience (communication fluency).
- Identify and gather information/data relevant to the essential question, issue, and/or problem and develop informed conclusions (critical thinking).
- Identify, utilize, and cite various sources of information in academic assignments, projects, or performances (information literacy).

e. Support of Other Majors/Minors

In addition to providing instruction for physics majors and minors, the Physics Program serves a significant number of students in other programs at CMU. In the AY 2020-2021, Physics courses had a total enrollment of 1,405 students corresponding to 3,690 student credit hours.

Many physics courses are required or listed as options by other degree and minor programs. See Table 1 for a complete listing. In addition, several physics courses service the University's Essential Learning Curriculum.

Table 1: Physics Courses Supporting Other Degree and Minor Programs

PHYS	Programs Listing Course as a Requirement	Programs Listing Course as an Option
100		Essential Learning A.S. – Agriculture Science
101	B.S. – Education: Secondary Education, Geosciences	Essential Learning B.S. – Education: Secondary Education, Biological Sciences

111, 111L	B.S. – Biology B.S. – Cellular, Molecular, and Developmental Biology B.S. – Ecology, Evolution, and Organismal Biology B.S. – Education: Secondary Education, Geosciences A.A.S. – Land Surveying and Geomatics	Essential Learning B.S. – Biochemistry B.S. – Chemistry B.S. – Construction Management B.S. – Education: Secondary Education, Biological Sciences B.S. – Environmental Geology B.S. – Geology A.A.S. – Mechanical Engineering Technology
112, 112L	B.S. – Biology B.S. – Cellular, Molecular, and Developmental Biology	Essential Learning B.S. – Biochemistry B.S. – Chemistry B.S. – Education: Secondary Education, Biological Sciences B.S. – Environmental Geology B.S. – Geology
131, 131L	B.S. – Civil Engineering B.S. – Electrical /Computer Engineering B.S. – Mechanical Engineering B.S. – Mechanical Engineering Technology	Essential Learning B.S. – Biochemistry B.S. – Chemistry B.S. – Environmental Geology B.S. – Geology A.A.S. – Mechanical Engineering Technology B.S. – Mechanical Engineering Technology
132, 132L	B.S. – Civil Engineering B.S. – Mechanical Engineering B.S. – Electrical /Computer Engineering	Essential Learning B.S. – Biochemistry B.S. – Chemistry B.S. – Environmental Geology B.S. – Geology
230		B.S. – Electrical /Computer Engineering B.S. – Mechanical Engineering
231		B.S. – Electrical /Computer Engineering B.S. – Mechanical Engineering
471		B.S. – Applied Mathematics
ESSL 290		Essential Learning

f. Locational and Comparative Advantages

Colorado Mesa University is a regional educational provider, with a service area of fourteen counties that span a geographic area of 30,000 square miles, making up nearly 30% of the State of Colorado. CMU students come from a wide variety of backgrounds that increase the diversity of the student population. Approximately 31% of students are Pell-eligible, 47% are first-generation, and 30% are minorities. CMU has made affordability a priority and has worked to keep education costs down by having one of the lowest rates of undergraduate tuition and fees in the state.

g. Ways Program Engages Students from Diverse Backgrounds

A strength of the Physics Program is the substantial student-teacher interaction and engagement in small upper-level classes and supervised research. However, recruitment of students into the Physics Program, especially students from underrepresented groups, has historically been a challenge. The Physics Program recognizes that a diverse faculty better engages students from diverse backgrounds. The goal of increasing diversity amongst our physics students has been assisted by the hiring of Dr. Youngmin Kim in AY 2019-20 and Dr. Catherine Whiting in AY 2020-21. A crucial step in recruiting students into the Physics Program is to provide a positive experience with physics early in the students' education. The new faculty members share duties in teaching introductory physics courses to a large number of first-year students. It is our hope that greater faculty diversity will encourage students from underrepresented groups to pursue a degree in physics.

h. Unique Characteristics

The Physics Program provides quality research opportunities for all physics majors, who are required to complete a full year of research before graduation. All tenured/tenure-track physics faculty are actively engaged with current physics research and supervise student research projects in a broad range of physics areas. In addition to fluency with the major fields of physics and supervised research projects, the Physics Program works diligently to foster every student's oral and written communication abilities with appropriate coursework throughout the curriculum.

2. Curriculum

a. Breadth/Depth of Program

The Colorado Mesa University Physics Program offers a Bachelor of Science (B.S.) in Physics, an Associate of Science (A.S.) in Liberal Arts with an emphasis in Physics, and a Minor in Physics. The B.S. degree provides a comprehensive foundation for graduates wanting to pursue graduate programs or to seek employment in a variety of careers including work in industry, engineering or research. The A.S. degree is a two-year degree program intended to prepare students for further study towards a four-year degree. It includes a statewide common core of general education curriculum that meets the lower-division requirements of most baccalaureate degree programs in public higher education institutions in Colorado. There are several introductory courses that satisfy diverse needs of science and non-science students such as the PHYS 111/112 (algebra-based introductory physics) courses that are required for biology, geology and construction management (PHYS 111 only). The PHYS 131/132 (calculus-based introductory physics) courses are required for engineering and other science majors. These courses also satisfy the essential learning requirement of "Natural Sciences" courses with a lab component.

The courses comprising a B.S. in Physics include: 1) foundation courses and laboratories (CSCI 111 or CSCI 110/110L, PHYS 131/131L, PHYS 132/132L), 2) core courses that provide foundational concepts in classical mechanics, electricity/magnetism/optics, quantum mechanics, statistical/thermal physics, 3) laboratory courses beyond freshman level: Electronics for Scientists, Intermediate Laboratory, and Advanced Laboratory, 4) restricted electives and special topics given in solid state physics, modern optics, general relativity and quantum optics and quantum information, and 5) senior research and seminar. All physics majors are required to take two semesters of research (PHYS 482), which entails working on a research project supervised by one of the physics faculty, and two semesters of seminar (PHYS 494). Physics majors are required to present their research at one of the physics seminars (PHYS 494) and to the greater campus community at the CMU Student Showcase. It should be noted that the required physics seminar presentation is approximately 45 minutes in length with 3-5 minutes allotted for questions. CMU physics students also sometimes participate in summer research programs at other institutions typically via the NSF REU program.

Currently, the physics program has five tenured/tenure-track faculty actively engaged in research. The tenure-track faculty have professional training and research specialties in material science and nanotechnology, general relativity and gravitation, theoretical quantum computing and quantum information, and experimental quantum phenomena in the solid state.

b. Program Currency

Since the last program review in AY 2012-2013, the CMU's Physics Program now offers a distinct Bachelor of Science degree in Physics instead of the previously offered Bachelor of Science in Physical Sciences with a concentration in Physics. The B.S. in Physics was formally introduced in AY 2013-14. The B.S. in Physical Sciences with a concentration in physics was gradually phased out with the last degree awarded in AY 2016-17.

Prior to AY 2012-2013, PHYS 422 - Quantum Theory II and PHYS 473 - Modern Optics were both required for the B.S. degree. Subsequently, the Physics Program dropped this requirement and created a rotating set of "Restricted Electives", where any two of these courses are now required for the B.S. in Physics degree. PHYS 422 and PHYS 473 are now two options out of several possible course offerings. This change has provided flexibility for both the students and the physics faculty. These restricted electives are taught by faculty with expertise in solid state physics, general relativity, computational physics, and theoretical/experimental quantum optics and quantum information. Additionally, the B.S. in Physics degree now requires CSCI 111 - Foundations of Computer Science or CSCI 110 - Beginning Programming and CSCI 110L - Beginning Programming Lab, which are listed as part of our "Foundational Courses". It is the goal of the Physics Program to offer PHYS 471 – Computational Physics to every physics major at CMU, implying that the program intends to offer this course at least every other year.

Two replacement tenure-track faculty members have joined the program within the past two years, consequently strengthening the program by adding needed diversity in both faculty composition and research offerings. Currently, the Physics Program has five tenured/tenure-track professors, one full-time non-tenure-track instructor and one full-time visiting assistant professor as well as several rotating adjunct instructors.

c. Description of Program Delivery Locations and Formats

All physics courses are delivered in traditional classroom and laboratory settings on CMU's main campus. The algebra- and calculus-based introductory physics courses (PHYS 111/112 and PHYS 131/132) are typically taught in sections of 40 or fewer students with the accompanying laboratory courses capped at a maximum of 24 students per lab section. PHYS 230 - Intermediate Dynamics, PHYS 231 - Modern Physics, PHYS 251 - Electronics for Scientists, and PHYS 252 - Intermediate Laboratory are the lecture and laboratory courses typically taken during the sophomore year. While the freshman-level laboratory courses that accompany PHYS 111/112 and 131/132 are taught as one-credit-hour courses, the sophomore-level labs and PHYS 331 - Advanced Laboratory are taught as three-credit-hour courses. PHYS 311 - Electromagnetic Theory I, PHYS 321 - Quantum Theory I, PHYS 342 - Advanced Dynamics, and PHYS 362 - Statistical and Thermal Physics constitute the core major courses and are taken during the junior and senior year. Students must choose two restricted electives from a variety of courses offered including PHYS 312 - Electromagnetic Theory II, PHYS 372 - General Relativity, PHYS 422 - Quantum Theory II, PHYS 441 - Solid State Physics, PHYS 471/472 - Computational Physics I/II, PHYS 473 - Modern Optics and PHYS 396/496 - Topics. These restricted electives rotate every semester and are typically taken during the junior and senior year. Two semesters of both PHYS 482 - Senior Research and PHYS 494 - Physics Seminar constitute our capstone experience and are required of all physics majors seeking the baccalaureate degree.

Many of our lecture courses and all of our laboratory courses are held in Wubben Hall. This allows classroom demonstrations and lab preparations to be carried out more efficiently. During the past eight years of the review period, the Physics Program has awarded an average of 4.5 bachelor degrees per year.

3. Analysis of Student Demand and Success

a-d. Enrollment, Student Credit Hours, and Graduates

The following data are representative of the period from AY 2013-14 through AY 2020-21. Program-specific tables are provided in this section and some additional data tables are provided in the appendices.

The Physics Program experienced a 31% increase in the average number of B.S. majors, from 41.6 in the review period of AY 2013-14 through AY 2020-21, compared to an average of 31.8

in the prior review period of AY 2008-09 through AY 2012-13. Table 2 shows the number of physics majors and graduates at the beginning and end of the review period as well as the averages. The decrease in declared B.S. majors of 28% during the current review period, from 43 in AY 2012-13 to 31 in AY 2020-21 is due to several factors, which will be discussed in what follows. Chart 1 shows both the total number of physics majors and B.S. degrees awarded versus academic year for the review period. Notice that the total number of physics majors per academic year is essentially flat over the period of this review, with the exception of AY 2019-2020 and AY 2020-21, where a drop of 33% from AY 2018-19 to AY 2020-21 occurs. This decrease coincides with the program graduating a relatively large number of students and the onset of the COVID-19 pandemic. Although the decrease over the last two years is bothersome and likely heavily influenced by the COVID-19 pandemic, we are hopeful that the number of graduates will increase over the next review cycle.

Table 2. Summary of Physics Majors and Graduates by Degree

Degree Program	Number of Declared Majors				Annual Number of Graduates			
	Annual Average	AY 2012-13	AY 2020-21	% Change AY 2012-13 – AY 2020-21	Low	High	Total	Average
B.S.	41.6	43	31	- 28%	3	6	36	4.5
Minor	4.4	3	7	+ 133%	0	2	4	0.5
A.S.	6.4	10	2	- 80%	0	2	5	0.6

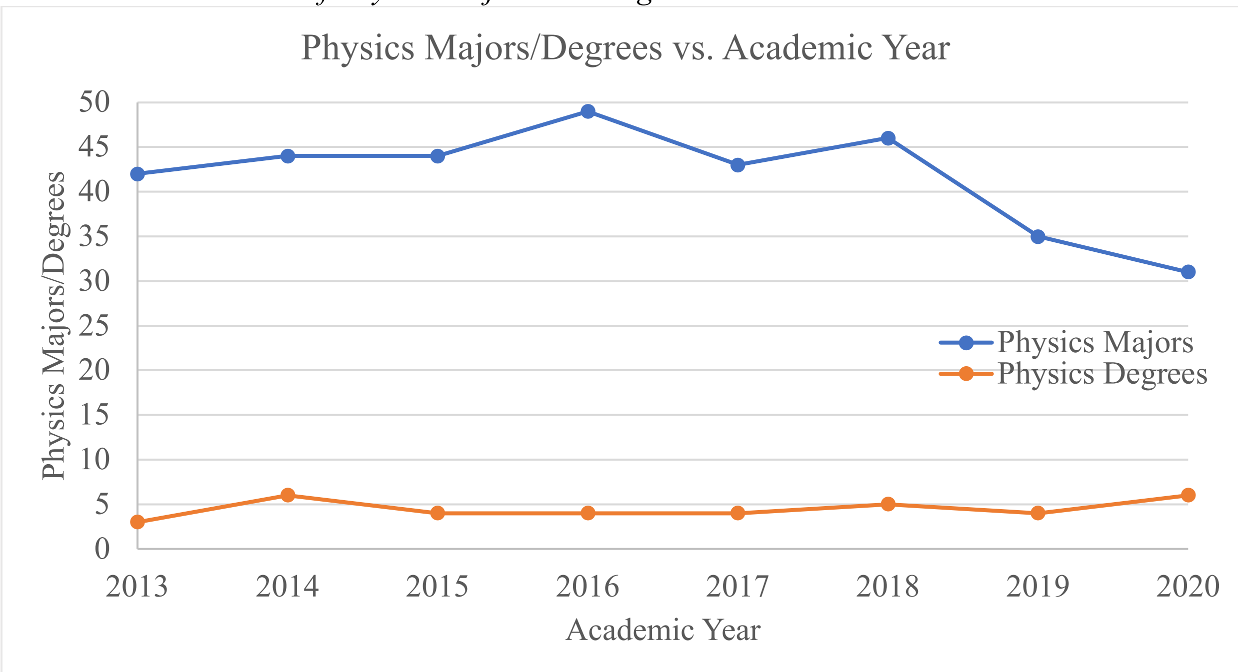
A total of 36 physics majors graduated with a B.S. degree during the eight-year review period with an average of 4.5 per year, which can be seen in Chart 1. This corresponds to an 18% increase over the prior review period as the Physics Program previously graduated 3.8 per year during the prior review period. It should be noted that in AY 2013-14, the B.S. in Physics was introduced to replace the B.S. in Physical Sciences with a physics concentration. Consequently, the physics major code was changed and the B.S. in Physical Sciences with a physics concentration was phased out completely prior to the start of AY 2017-18. The total number of B.S. majors included in this report is the sum of those labeled by the two codes.

The number of A.S. degree majors decreased by 80%, as there were 10 in AY 2012-13 and only 2 in AY 2020-21. The number of A.S. degrees awarded during the review period remained low, with a total of 5 graduates in the eight-year period, consistent with the prior five-year review period when only 3 A.S. degrees were awarded.

There was a 133% increase in the number of students declaring physics as a minor during the review period, with an annual average of 3.9 students. However, only four total students completed a physics minor during the eight-year review period. It should be noted that many of the students who pass through the PHYS 131/132 sequence, who appear to be a potential source of physics minors, are pursuing one of the engineering degrees from the CMU/CU Boulder

Partnership Program. These students are ineligible to formally minor in physics as their B.S. degree is ultimately awarded from the University of Colorado.

Chart 1: Total Number of Physics Majors and Degrees Awarded vs Academic Year



The Physics Program experienced significant changes in the latter half of the review period. Two faculty members took a sabbatical leave for one semester each, in AY 2016-17 and AY 2019-20, one tenured faculty member resigned unexpectedly just before the start of AY 2019-20, and two new tenure-track faculty members were hired in AY 2019-20 and AY 2020-21. The apparent dip in numbers of declared physics majors in AY 2019-20 and AY 2020-21 could potentially be explained from these significant changes. The sabbatical leave of two tenured faculty members meant that the other full-time faculty took on heavier or more upper-level course loads during those semesters, that fewer major core courses could be offered, and that the rest of the offered courses were filled by temporary faculty. One upper-level physics course was cancelled completely in AY 2019-20 due to the sudden resignation of one tenured faculty member. Additionally, AY 2019-20 and AY 2020-21 were significantly impacted by COVID-19, where the overall numbers of students enrolled at CMU decreased during these years. We anticipate modest growth in the number of physics majors in the next few years, due to the hiring of two new tenure-track faculty members, the development of a new astronomy course with a lab component, as well as a plan to offer new astronomy focused senior research projects utilizing the revitalized partnership with the Falcon Telescope Network.

Average course enrollments remained relatively constant throughout most of the review period but decreased overall by ~7% from AY 2013-14 to AY 2020-21. Chart 2 shows both the total student credit hours (SCH) and total enrollment in physics courses plotted versus academic year during the review period. Table 3 shows total enrollment and SCH by both student and course level. The large decrease in freshman enrollment and student credit hours can be partially explained by the fact that the Liberal Arts, Elementary Education major stopped requiring PHYS 100 for all three concentrations (English, Mathematics, and Social Science). This course was required for all elementary education majors seeking the B.A. degree until AY 2018-19. Prior to this change, the course's enrollment was consistently around 100 per semester, but following this change the enrollment dropped significantly to roughly 30 per semester. Additionally, we have witnessed a decrease in enrollment in PHYS 131 during the AY 2019-20 and AY 2020-21, surely influenced by the COVID-19 pandemic and the decrease in total students enrolled at CMU. However, there has been an increase in enrollment in 400-level courses, indicating slightly more graduating majors and perhaps a greater interest amongst students in taking upper-level physics courses.

Chart 2: Student Credit Hours (SCH) and PHYS Total Enrolled vs Academic Year

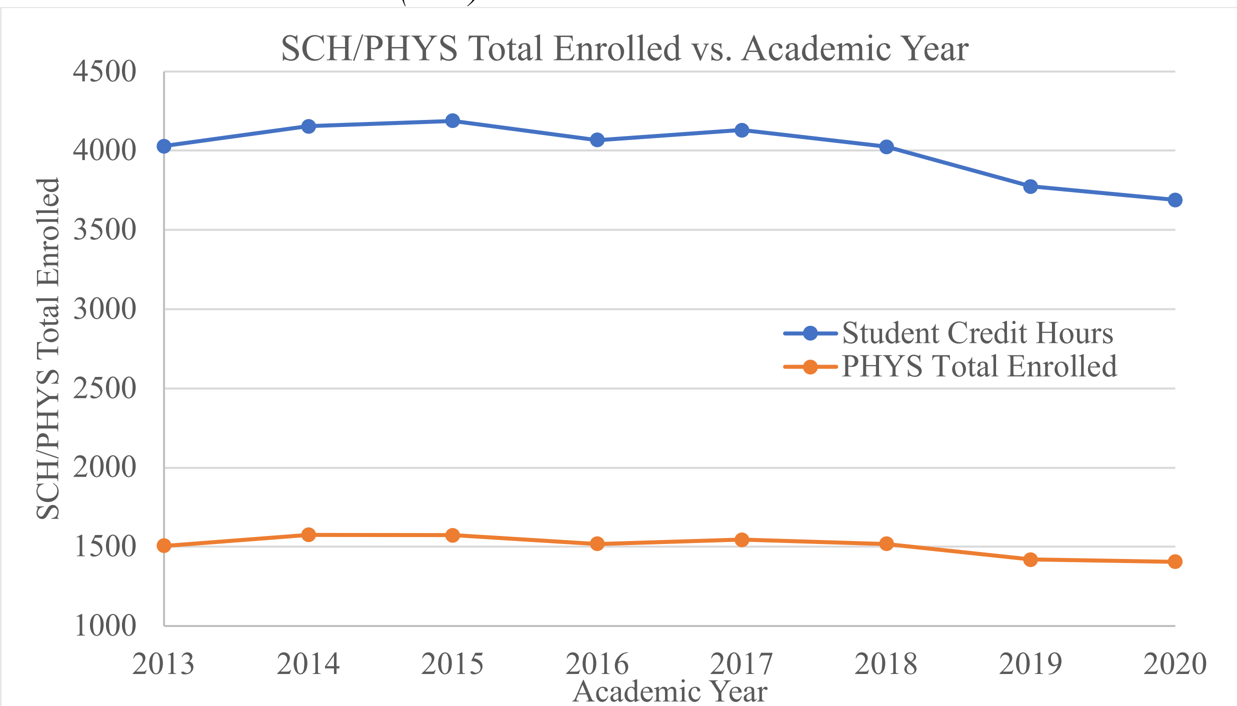


Table 3. Enrollment and Student Credit Hours (SCH) by Student and Course Level

Physics	Annual Average AY 2013-14 – AY 2020-21	AY 2013-14	AY 2020-21	% Change AY 2013-14 – AY 2020-21
Enrollment by student level				
Freshman	170	233	128	- 45%
Sophomore	460	461	400	- 13%
Junior	392	381	373	- 2.1%
Senior	477	431	492	+ 14%
Non-degree	9.6	0	11	+ 100%
Total	1508	1506	1404	- 6.1%
SCH by student level				
Freshman	478	646	358	- 45%

Sophomore	1231	1254	1060	- 15%
Junior	1034	1001	970	- 3.1%
Senior	1239	1128	1269	+ 13%
Non-degree	25	0	30	+ 100%
Total	4007	4029	3687	- 8.5%
Enrollment by course level				
100	1379	1373	1280	- 6.8%
200	56	52	36	- 31%
300	44	56	60	+ 7.1%
400	29	25	29	+ 16%
Total	1508	1506	1405	- 6.7%
SCH by course level				
100	3676	3665	3374	- 7.9%
200	163	150	108	- 28%
300	125	163	179	+ 9.8%
400	44	51	29	- 43%
Total	4007	4029	3690	- 8.4%

e. Student Successes and Recognition

Of the 36 graduates with a major in physics during the review period of AY 2013-14 through AY 2020-21, nine enrolled in graduate schools. One student enrolled in a Ph.D. program in physics and one student went into a Ph.D. program in materials science. Four graduates enrolled in M.S. programs. Four went into engineering programs, two into medical fields, two went into physics programs, and one went into an applied math program. 19 students who graduated with a major in physics are known to have been employed at some time after graduation in a field related to STEM or medical disciplines.

Six students were co-authors on publications in peer-reviewed international journals during AY 2013-14 through AY 2020-21. Over the past eight years of the review period, 25 students gave presentations at the CMU Student Showcase. One of these presentations was virtual in AY 2019-20 and one was a co-presenter in AY 2013-14. In addition, one student presented at a regional physics conference, the 2014 APS Four Corners Meeting at Utah Valley University, one student presented a poster at the Spring 2014 SPS Zone 14 Regional Meeting, one student presented a poster at Physics Congress (Phys Con) in 2016 in College Park, MD, and one student coauthored a virtual presentation at the APS Division of Fluid Dynamics (DFD) 2020 meeting and gave a virtual presentation at the APS March 2021 meeting. The student presenting at the SPS Zone 14 meeting placed as runner up for the best undergraduate poster presentation. Four students won best poster presentation and one student won best oral presentation at the CMU Student Showcase in various years during the review period.

During the review period, a total of 16 students were inducted as members into Sigma Pi Sigma, organized by the American Institute of Physics. The average number of students inducted per year was two, which is the about the same as the prior review period.

4. Program Resources

a. Faculty

Faculty headcount, rank, and qualifications

During the academic year (AY) 2020-21, the Physics Program had seven full-time faculty members with five of them, or 71%, being tenured or tenure-track. These numbers mark an increase in both categories of faculty members, but a slight decrease in the percentage of tenured or tenure-track when compared with AY 2012-13, when the physics program had five full-time faculty members with four of them, or 80%, being tenured or tenure-track. See Table 4 for a complete breakdown of tenured, tenure-track, and full-time, non-tenure-track faculty members.

Table 4: Composition of Physics Faculty in AY 2012-13 and AY 2020-21

	AY 2012-13	AY 2020-21
Tenured	3	3
Tenure-track	1	2
Full-time, non-tenure-track	1	2
Total	5	7

At the completion of the spring semester of 2017, one tenured faculty member retired. Immediately prior to the fall semester of 2019, one tenured faculty member resigned unexpectedly. After a couple of years of failed searches, the Physics Program has successfully filled both tenure lines with the addition of Dr. Youngmin Kim, an experimental physicist, who started in the fall semester of 2019 and Dr. Catherine Whiting, a theoretical physicist, who began in the fall semester of 2020. These additions have added needed diversity to our program where we now have two analytical theorists, one computational/analytical theorist, and two experimental physicists amongst the tenured and tenure-track faculty.

All current tenured, tenure-track, and full-time, non-tenure-track faculty members in the Physics Program have a Ph.D. in physics. A complete listing of these faculty members and their vitae can be found in the appendices.

Credit hour generation

The number of full-time equivalent students (FTES) and full-time equivalent faculty (FTEF) for AY 2013-14 and AY 2020-21 are displayed in Table 5. Notice that FTES decreased slightly from 134.3 in AY 2013-14 to 123.0 in AY 2020-21 whereas FTEF remained constant at 6.1. The ratio of FTES to FTEF was 22.1 in AY 2013-14 and 20.2 in AY 2020-21, which corresponds to a decrease of 8.6%.

Table 5: Full-Time Equivalent Students and Faculty for AY 2013-14 and AY 2020-21

	AY 2013-14			AY 2020-21			Percent Change in FTES:FTEF[3] from AY 2012-13 to AY 2020-21
	FTES[1]	FTEF[2]	FTES: FTEF[3]	FTES[1]	FTEF[2]	FTES: FTEF[3]	
Physics	134.3	6.1	22.1	123.0	6.1	20.2	- 8.6%

[1] Full-time equivalent students

[2] Full-time equivalent faculty

[3] Ratio of full-time equivalent students to full-time equivalent faculty

Total student credit hours generated by faculty type as a percentage of the total is displayed in Table 6 over the period of this review. Notice that total student credit hours per academic year are essentially flat over the period of this review, with the exception of AY 2019-2020 and AY 2020-21, where a decrease of ~8% of total student credit hours occurred. This decrease can be partially explained by the sudden resignation of a tenured faculty member, which occurred two-weeks prior to the start of the fall semester of 2019 and unfortunately coincided with the start of another faculty member's sabbatical (Dr. Middleton). This left the Physics Program understaffed and forced the abrupt cancelation of one physics course (PHYS 471 – Computational Physics I). This event also explains the increase in the percentage of credit hours taught by part-time faculty as an adjunct instructor was hired to cover one section of PHYS 101 – Elementary Astronomy, which had an enrollment of 92 students. It is noted that the decrease in total student credit hours that began in AY 2019-20 coincides with the onset of the COVID-19 pandemic.

Table 6: Percentage of Student Credit Hours Generated by Faculty Type, AY 2013-14 through AY 2020-21

Academic year	Total student credit hours	Tenured/tenure-track	Full-time, non-tenure-track	Part-time
2013-2014	4029	72%	18%	10%
2014-2015	4155	79%	18%	3%
2015-2016	4188	76%	19%	6%
2016-2017	4068	78%	16%	6%
2017-2018	4130	54%	41%	5%
2018-2019	4025	58%	36%	6%
2019-2020	3774	51%	36%	13%
2020-2021	3690	78%	15%	7%

Also notice that the percentage of credit hours taught by tenured and tenure-track faculty decreased from 78% to 54% and the percentage of credit hours taught by full-time, non-tenure-track faculty increased from 16% to 41% between AY 2016-17 and AY 2017-18. This change coincided with Dr. Collins' sabbatical leave during the spring semester of 2017, which was followed by the retirement of a tenured faculty member after the spring semester of 2017. A full-time, non-tenure-track faculty member (Dr. Jarrod Schiffbauer) was hired during this time. Although Dr. Schiffbauer remains on the faculty as a full-time Visiting Assistant Professor, currently teaching at a half-load capacity, the once open tenure line has been filled with the hiring of Dr. Kim.

Faculty success, quality, and recognitions

Teaching and scholarship

The tenured and tenure-track physics professors receive mostly 5s as the median of medians for their courses, with averages ranging from 4.25 to 4.75. Several professors routinely receive 5s for all of their courses. Both our full-time, non-tenure-track faculty receive an approximately equal number of 4s and 5s as the median of medians, with averages typically ranging from 3.5 to 4.5.

All tenured and tenure-track physics faculty regularly contribute presentations at the CMU Physics Seminar series. As all physics majors are required to complete two semesters of senior research, all tenured and tenure-track physics faculty members regularly mentor undergraduate research projects, where these students are required to present the results of their research at one or two CMU Physics Seminars and at the annual CMU Student Showcase.

Since arriving at CMU, Dr. David Collins has published six peer-reviewed papers, one with a CMU physics major as a co-author, and has given nine poster or oral presentations, mostly at major international conferences. Dr. Collins was awarded a sabbatical leave in the spring of 2017, where he joined the quantum information group at Universitat Autonoma de Barcelona. He has received three CMU exemplary faculty awards and has supervised 20 senior research projects.

Dr. Chad Middleton was awarded the 2017-18 CMU Associated Student Government (ASG) Faculty Member of the Year Award. He has received five Faculty Professional Development Grants while at CMU to support his research endeavors. Since arriving at CMU, Dr. Middleton has published nine peer-reviewed papers with seven CMU physics majors as co-authors and has given eleven oral presentations at regional, national, and international conferences. Dr. Middleton has received three CMU exemplary faculty awards and was granted a sabbatical leave in the fall of 2019.

Dr. Brian Hosterman has published four peer-reviewed papers since arriving at CMU in 2014. He has been awarded five Faculty Professional Development Grants to support his research and is a Co-PI on a successful grant through the Colorado Open Educational Resources program. Dr. Hosterman has supervised 11 student research projects.

Dr. Andy Shiekh has authored four peer-reviewed publications and given seven CMU Physics Seminars. Dr. Jarrod Schiffbauer has published seven peer-reviewed journal articles since arriving at CMU; an eighth article, with two CMU student authors, is currently in review. He has presented material at three national conferences, chairing one session and having a CMU student present a talk at a national meeting. Additionally, Dr. Schiffbauer has submitted a total of seven proposals for external federal funding and three proposals for internal/organizational funding. Of these, he has so far received funding for two NSF projects and one internally funded (faculty professional development) project; two additional NSF projects and one organizational project are currently pending. He was also recently nominated to Sigma Xi.

Advising

Students who decide to major in physics contact the administrative assistant in the Department of Physical and Environmental Sciences, who then enters this information into the campus-wide database and assigns them to a tenured or tenure-track professor for advising. The administrative assistant makes assignments so as to keep advising loads roughly equal, however, we do accommodate student requests for a specific advisor provided that the individual is not overloaded with advisees. Each tenured or tenure-track faculty member advises roughly five to fifteen students per semester. Students are not required to regularly see their advisor, but many of our majors do.

Service

Faculty in the Physics Program have been active in service to the university over the review period. All tenured and tenure-track faculty have participated in campus-wide committees, with several serving in leadership positions. Dr. Middleton served as the Faculty Senate president during the 2015-16 academic year and as the Faculty Trustee during the 2017-18 and 2018-19 academic years. Dr. Collins served as Faculty Senate president during the 2020-21 academic year. Dr. Hosterman served as chair of the Faculty Success Committee during the 2019-20 academic year.

The Society of Physics Students (SPS) received eight Distinguished Chapter Awards while Dr. Middleton was the Faculty Advisor. SPS received three Distinguished Chapter Awards and one Outstanding Chapter Award since Dr. Hosterman has become the Faculty Advisor.

b. Financial Information

Internal funding

The Physical and Environmental Sciences department head submits a budget request to administration each January for the upcoming financial year, which begins on July 1. Our working assumption is that the Physics Program will receive the same amount as the previous year. Requests for one-time funds or base-building increases are approved based on justification and availability of funds.

Table 7 shows the costs for the Physics Program in AY 2012-13 and AY 2019-20. Hourly compensation is for student assistants. Other current expenses include supplies, software, equipment purchase and repair, copier lease, and other similar costs. Travel costs in the budget allocation category refer to faculty travel. Internal charges are for phones and phone calls.

Chart 3 shows a plot of the ratio of the total expenditures per student credit hour (SCH) vs academic year. Notice that the total expenditures per student credit hour lie within the range \$100-\$122 with the exception of AY 2016-17 and AY 2019-20. For these academic years, the total expenditures per SCH were \$134 and \$135, respectively. These outliers can be partially explained by the fact that Dr. Collins and Dr. Middleton were on sabbatical leave for the spring of 2017 and fall of 2019, respectively.

The Faculty Professional Development Fund is a source of internal funding for tenured, tenure-track and full-time, non-tenure-track faculty employed at CMU. The upper limit of an individual award is $3,000 and typically falls in the $1,000-$2,000 range. These grants can be used to support faculty travel to conferences, purchase research equipment, etc. Five of the Physics Program faculty members have been awarded 15 grants during the review period.

Table 7: Expenditures in AY 2012-13 and AY 2019-20

Expenditures	AY 2012-13	AY 2019-20
Expenditure of Budget Allocation		
50000 Classified wages		$3,770
51460 Classified benefits		$2,128
52560 Regular wages	$246,265	$263,555
52860 Part-time wages	$48,945	$103,846
54160 Benefits	$79,627	$107,462
56000 Hourly compensation	$250	$2,209
61000 Other current expenses	$14,967	$6,390
61500 Travel	$1,361	$4,300
64010 Internal charges	$1,999	$1,998
Total	$393,414	$495,659
Expenditure of Course Fees		
61000 Other current expenses	$5,985	$12,903
Total	$5,985	$12,903
Total expenditure	$399,399	$508,562
Student credit hours (SCH) generated	3,982	3,774
Total expenditures per SCH	$100/credit hour	$135/credit hour

External funding

Some physics faculty members have applied for external funding to support their research endeavors and teaching excellence at CMU, which include:

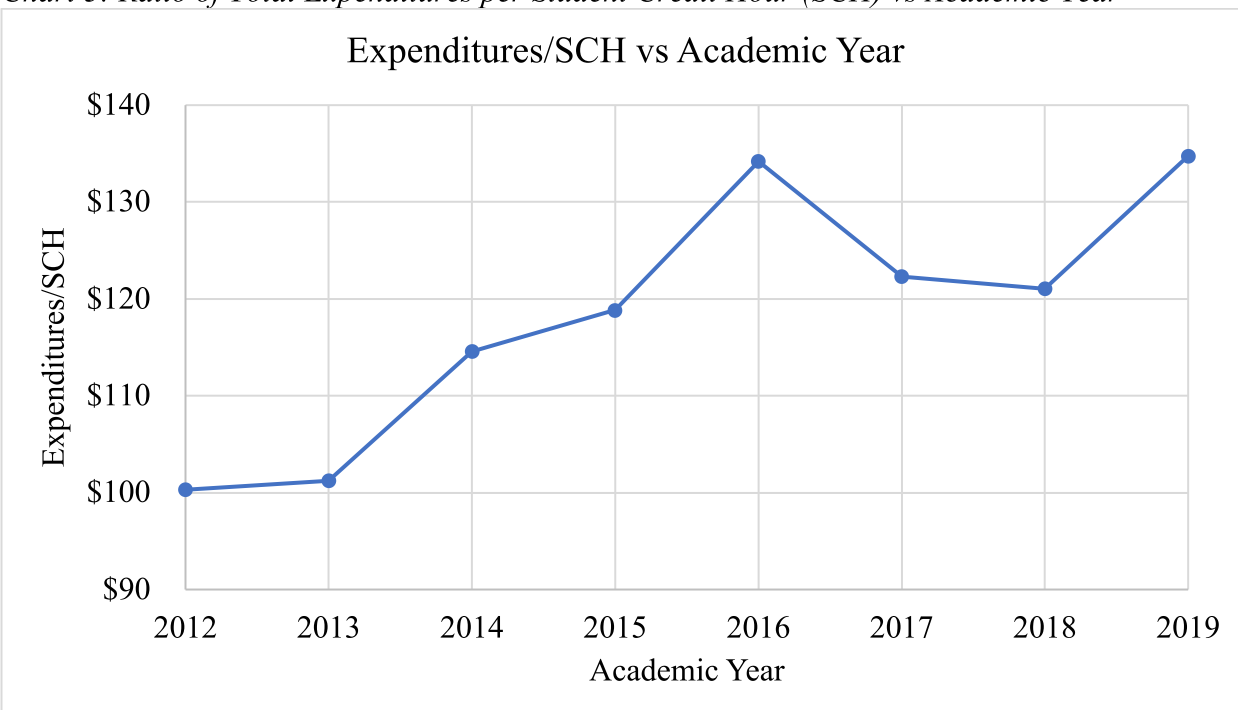
Dr. Schiffbauer (PI) was awarded $395,801 from the National Science Foundation (NSF) for "Collaborative Research: Using Molecular Functionalization to Tune Nanoscale Interfacial Energy and Momentum Transport" in 2020.

Dr. Schiffbauer (PI) was awarded $90,638 from the NSF for "EAGER: Collaborative Research: Dynamics of Nanoparticles in Light-Excited Supercavitation" in 2020.

Dr. Schiffbauer (PI) was awarded $49,771 from the NSF and Center for Advancement of Science in Space for "ISS: Collaborative Research: Individual and Collective Behaviors of Active Colloids in Microgravity" in 2021.

Dr. Kim (PI), Dr. Hosterman (Co-PI), and Dr. Whiting (Co-PI) were awarded $9,600 from the Colorado Department of Higher Education for “Developing and Implementing Open Education Resources (OER) Materials for GT-Pathways Introductory Physics Courses (PHYS 111, 112, 131, 132) at Colorado Mesa University” in 2021.

Chart 3: Ratio of Total Expenditures per Student Credit Hour (SCH) vs Academic Year



c. Library Assessment

The faculty view a strength of our library holdings to include access to Physical Review Online Archive (PROLA), which provides immediate access to APS journal collection dating back to the first volume of each journal. The physics faculty believe that we have a sufficient budget to purchase desired textbooks. Another perceived strength of the library is the staff's willingness to work with our students; the library staff are very willing, in general, to help students learn how to use all available library resources. A weakness of our library holdings is not having access to Physical Review Letters, which requires a very costly subscription. Additionally, the physics faculty have experienced inconsistent web access to subscribed journals. The interlibrary loan program often provides articles not held in the collection within 48 hours. While some access to these articles is commendable, this delay can hinder research and the composition of publications, especially since these activities commonly necessitate searching for a reference within a reference.

The assessments prepared by the Tomlinson Library are shown in Appendix C along with periodical lists. An excerpt from the report is included here.

Strengths: Journals, and books are important resources for physics faculty and majors. The indexing and full-text provided by CMU's database subscriptions provide access to much current scholarship in the field, strengthening the Library's resources for physics research. While not extensive, the Library's reference collection supports the need for authoritative concise information. The Library's e-book collection is strong in the sciences and physics is well represented. E-books on both general and esoteric topics are readily available. The Library's DVD, and Films on Demand collections provide useful resources, especially for general and introductory needs. The circulating physics book collection receives regular use and sufficiently supports coursework for undergraduate physics majors.

Weaknesses: As the physics monographic collection continues to be expanded, effort should be made to select materials that support less well represented or emerging subject areas, such as thermodynamics. If there is interest in media materials for more advanced students, additional materials could be purchased for this purpose.

d. Physical Facilities

Lecture courses are distributed among all classroom buildings on campus. All classrooms have computers, network and internet access, document cameras, and projection screens. Laboratory work is confined to the second floor of Wubben Hall, which is part of the Wubben Hall & Science Center. The labs were completed and occupied in 1997 and then renovated in 2011. Physics facilities include:

- one 24-student laboratory for freshman physics labs
- one electronics/intermediate laboratory
- one advanced physics laboratory
- two small research laboratories
- one physics stockroom

e. Instructional Technology and Equipment

Both theory and experiment are essential components of any science curriculum, and experimental work requires specialized scientific equipment. The Physics Program has a full complement of laboratory experiments with the necessary corresponding apparatuses. Our current laboratory facilities and computational equipment are deemed sufficient by the physics faculty for our program. Specialized equipment includes:

- one optical breadboard used for photon counting and interference experiments
- one optics table used for Raman spectroscopy and optical characterization
- one optics table used for photon coherence and single photon counting experiments
- one micro-Raman spectrometer for material characterization experiments
- one temperature-controlled sample stage that can be interfaced with spectroscopy experiments

- one confocal micro-photoluminescence setup for optical characterization
- one Michelson interferometer for 1st-order photon coherence experiments
- one time-correlated single photon counting module (TCSPC) and photon multiplier tubes (PMT) for single photon counting experiments
- one liquid nitrogen cryostat for superconductivity experiments
- one 20-inch research-grade Ritchey Chretien telescope (housed at the Grand Mesa Observatory)
- one computer with 64 GB of RAM, a single 10-core CPU (hyperthreaded) Intel Xeon Processor E5-2640 v4 @ 2.40 GHz with a Hitachi HUA72302 2 TB drive and a Samsung SSD 850 256 GB drive
- one iMac Pro with 128 GB 2666 MHz DDR4 RAM, a 3 GHz 10-core Intel Xeon W Processor and Radeon Pro Vega 56 8 GB graphics

f. Efficiencies in Program Operations

We strive for maximum efficiency in the operation of the Physics Program. In deciding on course offerings, we attempt to assign two sections of a given course offering to the same instructor, when possible, as this minimizes total preparation time. All of our introductory lab courses (PHYS 111L, 112L, 131L, and 132L) share the same room and some of the laboratory equipment, such as the Pasco interface system.

Our two experimental physicists, Dr. Hosterman and Dr. Kim, share some research equipment including two optical tables, a spectrometer from Princeton Instrument, and a temperature-controlled sample stage. Dr. Kim uses the furnace owned by the CMU/CU Boulder Partnership Program, which is located in Confluence Hall. Dr. Hosterman uses the x-ray diffractometer, which is located in Wubben Hall & Science Center but owned and maintained by the Geology Program.

5. Student Learning Outcomes and Assessments

a. Student Learning Outcomes

The programmatic student learning outcomes (SLOs) were first developed by the tenured/tenure-track physics faculty members during AY 2013-14. These addressed the institution-wide learning outcomes for Baccalaureate degrees: i) Specialized Knowledge/Applied Learning, ii) Quantitative Literacy, iii) Communication Fluency and iv) Critical Thinking. These were modified in AY 2020-21 to included additional SLOs that address two newer institution-wide learning outcomes: i) Personal and Social Responsibility and ii) Information Literacy. (A full description of these categories is available at: https://www.coloradomesa.edu/assessment/learning-outcomes/index.html). During AY 2013-14 the faculty identified five crucial learning outcomes for the Bachelor of Science in Physics degree and aligned these with the institution-wide learning outcomes. The two newer learning outcomes were added specifically in response to the newer institution-wide learning outcomes.

The following lists the program SLOs and indicates their alignment with institution-wide SLOs via the information in parentheses in the following list.

Student Learning Outcomes for the Bachelor of Science Physics Degree

A student who completes the B.S. in Physics will have demonstrated the ability to:

1. Show fluency with the major fields of physics (classical mechanics, electromagnetism, statistical physics and quantum theory). (Specialized Knowledge/Applied Learning)
2. Use mathematical representations to analyze physical scenarios. (Quantitative Literacy)
3. Use laboratory techniques to investigate experimentally physical phenomena. (Specialized Knowledge/Applied Learning)
4. Communicate effectively about topics in physics. (Communication Fluency)
5. Execute a project which addresses a significant and complex issue in physics. This project will integrate knowledge and techniques from different areas of physics. (Critical Thinking)
6. Reflect on ethical, social and civic issues in physics. (Personal and Social Responsibility)
7. Find information relevant to physics, evaluate this critically and apply the information. (Information Literacy)

The Physics Program mission statement stresses fluency with the major fields of physics, quantitative and analytical reasoning, laboratory skills, written and oral communication skills and physics research. The learning outcomes were chosen to align with these aspects of the program mission and have been extended to include two additional outcomes that are generally important.

The curriculum map, included in Appendix D, indicates which SLOs the various courses required for the BS Physics degree satisfy.

The chosen SLOs ensure that students graduating with the Bachelor of Science in Physics degree gain skills not only in specialized knowledge of the field but also in Applied Learning, Quantitative Literacy, Communication Fluency, Critical Thinking and these will prepare them well for careers outside of physics. The recent addition of two new SLOs will better prepare students in the realms of Personal and Social Responsibility and Information Literacy.

Additionally, the courses PHYS 100, 101, 111/111L, 112/112L, 131/131L, and 132/132L are all part of the University's Essential Learning curriculum and are aligned to meet the following Essential Learning SLOs: (1) Demonstrate investigative and analytical thinking skills to solve problems and (2) Select and use appropriate information or techniques in an academic project.

These are assessed elsewhere via student performance on physics problems that have a conceptual, analytical and quantitative nature. In this way the physics assessment regimen addresses the broad demands of such learning and ensures that students passing through introductory physics courses gain these skills.

b. Assessment of Student Learning Outcomes

The SLOs for the Bachelor of Science in Physics degree are assessed via standardized tests, exam questions, written reports and seminars produced by students. These assessments and the data that has been gathered from them are presented in full in the Program Outcome and Assessment report.

Each SLO, except for the single one involving a Capstone project is assessed twice, once at the beginning level and again at the advanced level. Assessment data has been presented to the physics faculty, who have met and discussed it. Similarly, the physics faculty have proposed and discussed modifications to the assessment plan which we hope to implement in the future.

SLO #1 Show fluency with the major fields of physics (classical mechanics, electromagnetism, statistical physics and quantum theory). (Specialized knowledge/applied learning)

At the beginning level the Force Concept Inventory (FCI) is administered to all students in PHYS 131 - Fundamental Mechanics at the beginning of the semester and again at the end of the semester. This test consists of 30 multiple choice conceptual questions that test concepts in classical mechanics involving kinematics, forces and energy. The normalized gain is computed for each student. This considers the number of additional correct responses that any student could obtain after taking the test for the first time and computes the fraction of such correct responses that the student did attain after taking the test a second time. Thus if the student attained n_1 correct responses on the first attempt and n_2 responses on the second attempt, that student's normalized gain is $(n_2 - n_1)/(30 - n_1)$. The FCI and this method of measuring performance is well established in the Physics Education Research community. A high-gain course will produce average normalized gains greater than 0.70 and a medium-gain course in the range 0.30 to 0.70.

Table 8: Normalized gain results for FCI administered to PHYS 131 students. The normalized gain is computed for each student and the average of all of these over the entire section is reported. The population is the number of students in the section who took the FCI twice.

	Section 1 Average normalized gain	**Section 1 Population**	**Section 2 Average normalized gain**	**Section 2 Population**
2021 Spring	0.27	33	0.33	20
2019 Fall	0.42	26	0.46	19
2019 Spring	0.48	82	Combined with section 1	
2018 Fall	0.46	22	0.54	40
2018 Spring	0.41	32	0.45	30

2017 Fall	0.50	25	0.57	30
2017 Spring	0.35		0.44	66 (both sections)
2016 Fall	0.29	30	0.44	24
2016 Spring	0.44		No section 2 offered	
2015 Fall	0.48	30	0.35	30
2014 Fall	0.48	27	0.46	32
2013 Fall	0.53	35	0.43	35

Table 8 shows that the FCI scores usually average in the region of 0.40 to 0.50 with occasional fluctuations. These indicate medium-gain relative to most other institutions. Research has indicated that such medium-gain performance is only attained with interactive learning strategies. The physics faculty have generally incorporated such strategies, including Think-Pair-Share conceptual questions or in-class group work, into introductory-level courses, and the data suggests that this has been valuable for student learning and fluency with introductory-level classical mechanics.

Our benchmark for this assessment has been an average normalized gain of 0.25. In the future we propose to increase this to 0.35, primarily to act as a constant check on this type of learning. We also propose to extract class average scores on each question, identify those for which the score is lower than 60% and determine whether these reveal areas in which learning is deficient.

At the advanced level the outcome has been assessed in PHYS 321 - Quantum Theory. The assessment plan had called for implementation of a standardized test of concepts that appear in quantum theory courses. However, this was replaced by the average class scores on a single question from a midterm exam. This question has focused on calculation of probabilities via wavefunctions. Table 9 provides the data for this assessment tool.

Table 9: The average score attained by each class on a selected PHYS 321 midterm exam question, covering wavefunctions and probability. The population data indicates the number of students taking the exam.

Semester	**Average Score (Percent)**	**Population**
2021 Spring	71	7
2020 Spring	79	9
2017 Spring	81	N/A
2015 Fall	79	6
2014 Fall	80	2
2013 Fall	70	8

The benchmark established for this was a class average of 70% and the course has always attained this. However, the data provided by this assessment tool has limited utility since it reflects only one aspect of quantum theory and cannot be used to ascribe any particular broad fluency with quantum theory.

Our conclusion was that this assessment tool must be replaced and we plan to use the Quantum Mechanics Concept Assessment (QMCA). This has been used elsewhere, research has been published on its effectiveness and data standards exist for student performance on it. The test covers material that students encounter in both PHYS 231 - Modern Physics and PHYS 321 - Quantum Theory and will provide a much more robust overview of student fluency with quantum theory. The test will be administered once at the end of the PHYS 321 course and the benchmark, informed by student performance reported in the literature will be that the class average for the test is 50%. Average scores from individual questions will be used to determine deficiencies in instruction is PHYS 231 and PHYS 321.

SLO #2 Use mathematical representations to analyze physical scenarios. (Quantitative literacy)

At the beginning level, this SLO has been assessed in PHYS 132 - Electromagnetism and Optics via a single midterm exam question that requires vector addition of electric or magnetic fields. The class average score for the question is calculated. The data shows that the average score has been in the range of 65% to 83%. Since 2016 the average score has been above 70%. This shows at least adequate performance on this single problem. The monitoring provided by this assessment has suggested that the presentation of vector addition problems in introductory-level courses has been satisfactory but could use some reinforcement.

The physics faculty felt that this test was perhaps too narrow and that the variability in the question between instructors and semesters compromised the value of the data. In the future the physics faculty will construct an exercise consisting of two standard questions that will be administered to the class near the end of the semester. The standardization should better reflect student learning of vector concepts.

At the advanced level, this SLO has been assessed in PHYS 311 - Electromagnetic Theory also via a single midterm exam question that requires vector calculus to address a question in electromagnetism. The class average score for this question is calculated and the data shows that the range has been from 63% to 86%. This shows generally adequate performance on this question. The small numbers of students in the class and the likely fluctuations in the nature of the question will likely generate the types of fluctuations seen in the data.

The physics faculty felt that this test was also too narrow and that the nature of the question would be highly variable between instructors and semesters. The faculty proposed that this assessment tool be replaced by a standardized test, consisting of several questions that better represent the scope of vector calculus used in electromagnetism, and that could be administered as a review. We hope to establish a benchmark after a few iterations of this test and subsequently use the results to target areas in that course which need to be strengthened.

SLO #3 Use laboratory techniques to investigate experimentally physical phenomena. (Specialized knowledge/applied learning)

At the beginning level this SLO has been assessed in PHYS 251 - Electronics for Scientists via a graded lab exercise. The data reveals that the class average has always been above 75% and most recently has exceeded 85% each semester. It was noted that the exercise was graded via the associated lab journal entry and this may reflect grades associated with the communication aspects of these journal entries.

The physics faculty felt that this assessment should be replaced by a standard exercise that only tests a particular experimental procedure in electronics. The exercise will be graded separately from any associated lab journal exercise and will then better reflect the student's understanding of experimental techniques.

At the advanced level the SLO has been assessed in PHYS 331 - Advanced Laboratory via a lab report produced for one of the experimental physics projects done in that course. This project has varied from year to year. The data reveals class average scores in the range of 82% to 92% with one instance of an average of 65%. The scores have steadily increased since 2015 and are now well beyond the benchmark that the program had established. This reflects the ever-increasing program emphasis on such project work and the associated communication. Students are consistently performing well according to the goals of this SLO.

Part of the grade for these reports reflects communication-aspect skills and in the future the plan will be modified so that the laboratory technique and analysis components of the report are assessed separately from the communication-aspect skills.

SLO #4 Communicate effectively about topics in physics. (Communication fluency)

At the beginning level, this SLO is assessed in PHYS 252 - Intermediate Laboratory via a laboratory report written in the style of a scientific journal article. The report grade is divided into three categories that deal with various aspects of writing. An average grade is obtained for the entire class for each category. The data shows average class scores in the categories ranging from 79% to 94% with one instance of an average score of 72%. There has been an increasingly heavy emphasis on the writing aspects of this course during the review period. Deficiencies have been identified and addressed in subsequent semesters using rubrics, available to students, which have undergone many revisions.

One concern of the physics faculty was that these reports pass through several drafts before they are graded and that they may therefore reflect instructor input. Such instructor input is generally important for the writing process and will mostly be maintained. However, the final report that the students produce during the semester will only pass through a single draft. The faculty have proposed that this report be used for the assessment tool as it will much better reflect student effort.

At the advanced level, this SLO is assessed in PHYS 494 - Physics Seminar. Physics majors are required to take this course twice. Each time, they have to give a 50-minute seminar on a topic in physics, frequently related to their senior research project. The seminars are open to the public and the students are graded, in three categories, by faculty members in attendance. The average grade for these seminars for all students who are taking the course for the second time is presented in the data. This should consist of the class average grade for each of the three categories although in some years this was replaced by a single average grade across all categories. These average grades have always exceeded 75% and are frequently above 85%. All instructors of this course have steadily increased the requirements for student preparation for the seminar and this is reflected in the generally excellent scores that students attain.

In both courses used to assess this SLO, our students' performance has generally been excellent. The faculty have routinely used previous student performance and assessments to modify the course demands so as to address deficiencies in student learning. We believe that this has succeeded and is one of the highlights of the program.

SLO #5 Execute a project which addresses a significant and complex issue in physics. This project will integrate knowledge and techniques from different areas of physics. (Critical thinking)

This SLO is assessed once only in PHYS 482 - Senior Research. This is a capstone course in which students conduct original research on a single project supervised by a single faculty member. All physics majors are required to take this course twice and the assessment applies the second time that they take the course. The assessment consists of grades for the final report, organized in various categories that consider the scientific aspects of the project and also the communication in the report. The data shows that the vast majority of students attain the 80% benchmark in the various categories and that they succeed in executing a meaningful research project.

This course has been revised substantially in the review period to strengthen the projects, the student effort and the communication about the project. These revisions have been based on the nature of previous student projects, assessments of their efforts and communication. The rubrics for assessing this course, communicated to the students, have been revised nearly every semester during this period. The physics faculty members have seen student presentations about most of their projects and the consensus is that there has been substantial improvement in this aspect of student learning and that it is now one of the highlights of the physics program.

One possible remaining deficiency was assessing each student's depth of understanding of the project. Undergraduate students cannot be expected to understand deeply all of the tools and background of their projects and the faculty felt that their understanding can range from very superficial to nearly complete. We plan to add an assessment item to the rubric for grading the project in order to provide a clearer view of this situation.

SLO #6 Reflect on ethical, social and civic issues in physics. (Personal and social responsibility)

This outcome was added in AY 2019-20. At the beginning level it is assessed in PHYS 231 - Modern Physics via a written assignment which asks students to analyze the ethical and social implications of a particular modern physics development. The assessment has been implemented once during the Spring 2021 semester, where it covered the role of Werner Heisenberg in German efforts to develop a nuclear weapon during World War II. The assessment asked for written responses to several aspects of this issue. This was done on a trial basis because we have never covered such material in our physics courses and the semester was affected by COVID-19 interruptions. The exercise was graded for extra credit on a pass/fail basis and consequently all students who participated received 100%. At this stage the data does not indicate anything about student attainment on this SLO. However, about 60% of the class took the test and answered the questions attentively. This has shown us the value of including such material in this type of course. In the future we plan to include more than one such topic and assignment an enhance the conceptual level of the related assessment exercise and grading scrutiny.

At the advanced level this SLO is assessed in PHY 331 - Advanced Laboratory via a written assignment which analyzed the responsibility of journal coauthors in the well-known semiconductor research fraud committed by Jan Schon. This assessment has also only been implemented once in the Spring 2021 semester with the same constraints and on the same trial basis as that for PHYS 231. The assignment generated similar results to that for PHYS 231 although a larger fraction of students participated. The conclusions from this are similar to that for PHYS 231.

SLO #7 Find information relevant to physics, evaluate this critically and apply the information. (Information literacy)

This outcome was also added in 2020. At the beginning level it is assessed in PHYS 252 - Intermediate Laboratory via journal reference searches, the results of which are included in a laboratory report. This aspect of the report is graded. The class average score was 82% indicating satisfactory student learning in this respect.

At the advanced level this outcome is assessed in PHY 331 - Advanced Laboratory via journal references in a single laboratory report. The class average was 92% although this may have reflected other aspects of the report writing.

In both cases, during the review period the program has steadily increased standards for finding and describing existing information in student work in laboratory courses. Prior to the implementation of this new SLO students had already been graded on this and generally have performed well, indicating that they are able to locate meaningful information. We propose increased demands that ask students explicitly to evaluate this information. This will be implemented in PHYS 482 - Senior Research rather than PHYS 331 and we plan to modify the assessment plan to reflect this.

c. Program Improvements from Assessment of Student Learning Outcomes

The major program improvements resulting from assessment of student learning outcomes have addressed communication (PHYS 252 - Intermediate Laboratory, PHYS 331 - Advanced Laboratory, PHYS 482 - Senior Research, and PHYS 494 - Physics Seminar) and also student research (PHYS 482 - Senior Research).

The program has steadily increased the detailed scrutiny of written work in the laboratory courses and the research course. This has been based on observations of student work in previous semesters and has led to increasingly detailed rubrics, which are communicated to students and are used to inform feedback given to students. The program faculty consensus is that the quality of written student work has improved markedly during this period.

Similar increasingly detailed scrutiny has been applied to student seminars and capstone research projects and the faculty consensus on the quality of student work matches that for the written work.

d. Refinement and Modification of Data Collection.

The physics faculty feel that many of the assessment tools that have been used during the review period are inadequate and must be modified. In general, assessment tools that consist of a single question on an exam will be replaced by a standardized set of questions. These will reflect the learning outcome more broadly and provide a more stable base for comparison as semesters pass. Details about each of these proposed modifications are provided in the six-year assessment report. The faculty also plan to meet more frequently to discuss the data and assessment tools in the future.

6. Future Program Plans

a. Vision for Program

The Physics Program strives to create a positive and individualized learning environment for students of all backgrounds via small classes paired with supervised projects that allow for an abundance of student-faculty interaction. We plan to continue to offer a wide range of undergraduate course and research options. Since the last program review, the program has modified the baccalaureate degree to allow for increased flexibility in course offerings. Previously, PHYS 422 – Quantum Theory II and PHYS 473 – Modern Optics were required for the B.S. degree. Now, these two courses equate to two of seven "Restricted Electives" courses. We desire to grow both the total number of physics graduates and the number of physics graduates from underrepresented groups. With the recent hiring of a theoretical physicist with a background in astronomy and cosmology, we are currently exploring the feasibility of first developing an introductory astronomy course with a laboratory component and then later developing upper-level course options in astronomy. We are interested in potentially, eventually offering a minor in astrophysics or a concentration in astrophysics for the physics baccalaureate-seeking students.

b. Strengths and Challenges Facing Program

The Physics Program has many strengths, yet faces several challenges. One of our strengths includes the diversity of faculty expertise in regard to teaching and research. Out of our five tenured/tenure-track faculty, two are experimental physicists, two are analytical theorists, and one is a computational/analytical theorist. Our faculty have research interests and expertise in quantum computing and quantum information, quantum light-matter interactions in solid state, material science and nanotechnology, and general relativity. This diversity of our physics faculty enables us to not only adequately staff our intermediate and advanced laboratory courses (PHYS 251 – Electronics for Scientists, PHYS 252 – Intermediate Laboratory, and PHYS 331 – Advanced Laboratory) and our computational physics courses (PHYS 471/472 – Computational Physics I/II), but to also offer a varied selection of restricted electives and topics courses.

Additionally, this diversity in faculty expertise allows our program to offer a wide range of undergraduate research opportunities.

Our tenured and tenure-track physics faculty agree that another strength of our program, possibly our greatest strength, is the capstone experience that we offer our baccalaureate-seeking students. All physics majors pursuing the baccalaureate degree must complete two semesters of PHYS 482 – Senior Research and two semesters of PHYS 494 – Physics Seminar, which are typically taken during their final year of study. PHYS 482 - Senior Research offers physics majors the opportunity to conduct original research under the guidance of a physics faculty member. This course has been revised substantially during this review period in an effort to strengthen the projects themselves and the students' communication about their research projects. In PHYS 494 – Physics Seminar, each student must give one 50-minute presentation per semester. During the first pass through this course, Physics Seminar students may give a presentation on the current status of their senior research project or on a physics topic of their choice, with the consent of the instructor. During the students' second pass through Physics Seminar, students must present on their senior research project. Additionally, all students enrolled in Physics Seminar in the spring semester must present either an oral or poster presentation at the annual CMU Student Showcase. The physics faculty have seen many student presentations and the consensus is that there has been substantial improvement in the quality of both the research performed and the presentation of this research. Several of our senior research students (~ 20% during this review period) have co-authored a peer-reviewed publication with their research advisor and some have presented at regional and national conferences since the last program review.

Another strength of the Physics Program includes the close interactions between the physics faculty and students. Class sizes in upper-division physics courses are small, creating a positive and intimate learning environment, and students are generally welcome to approach physics faculty with questions regarding their coursework. In our alumni survey, 78.9% of the physics alumni that responded indicated that they "Very Often (at least once a week)" had conversations with the faculty outside of class, compared to 38.2% of the general CMU alumni response.

The faculty agree that the Physics Program has sufficient experimental lab equipment for both undergraduate courses and research. Since the last program review, the Physics Program has placed a priority on obtaining the necessary lab equipment and has done so using mostly existing program resources. Additionally, CMU has entered into the Falcon Telescope Network with the United States Air Force Academy in Colorado Springs, where research and outreach opportunities are being developed by Dr. Whiting. Students at CMU will have access to several 20-inch research-grade Ritchey Chretien telescopes, with one located right near Grand Junction at the Grand Mesa Observatory.

Lastly, the Physics Program at CMU has developed and cultivated a strong local chapter of the Society of Physics Students (SPS). This club is arguably one of the most active on campus and has served the program in helping to build and strengthen the physics' student community. The CMU SPS chapter holds regular meetings accompanied by physics-related activities and demonstrations. With the exception of the past three semesters due to the COVID-19 pandemic, SPS hosts an annual pumpkin drop event on or near Halloween and an annual egg drop competition, where 50-100 middle school students compete in designing an egg drop contraption that will keep 1-3 eggs safe as they fall to the ground from a Genie S 60 ‘cherry picker’ at an initial height of approximately 50 feet. In the spring of 2018, SPS hosted the SPS Zone 14 (Colorado and Wyoming) Regional Meeting.

The Physics Program also faces several challenges. First and foremost, our program continuously struggles to attract a robust number of physics majors and an adequate number of students from underrepresented groups (e.g. racial and ethnic minorities and women). Additionally, the lack of a dedicated classroom for our introductory physics courses is far from ideal as it makes the addition of classroom demonstrations difficult and sometimes nearly impossible. The lack of a laboratory coordinator also presents a challenge for the physics faculty as the set up and tear down of labs is essentially left to the individual lab instructors. As some of our introductory labs are taught by adjunct faculty, the lack of a lab coordinator often equates to a tenured or tenure-track faculty member having to oversee this process. Finding qualified adjunct instructors to teach some of our laboratory courses is always difficult for our Program Coordinator as Grand Junction lacks physicists with a masters’ or Ph.D. degrees who are willing to teach a laboratory class for $750 (Master’s degree) or $850 (Ph.D.) per credit hour per semester. Lastly, the inflexibility of our Information Technology department in allowing our physics faculty administrative privileges makes it incredibly challenging in obtaining needed software on laboratory and classroom computers in a timely manner. Additionally, the inflexibility of the Purchasing department regarding industry-standard licensing agreements severely limits our choices of equipment and software. As an example, the Physics Program attempted to purchase a single-user license of Wolfram Mathematica for Dr. Whiting, which ultimately required a CMU presidential override, leading to a six-month delay hindering her and her students’ research endeavors. She is currently facing the same issue with astronomy software.

c. Use of Program Review Process to Improve Teaching and Learning

During the self-study phase of the physics program review and the writing of the six-year assessment report summary, the physics faculty met to revisit and improve our current assessment plan. Some of these revisions have yielded improvements and efficiencies to the courses themselves. As an example, *SLO #4 Communicate effectively about topics in physics (communication fluency)* is assessed at the beginning level in PHYS 252 – Intermediate Laboratory via a report written in the style of a scientific journal article. Typically, Intermediate Laboratory reports pass through several iterations before they are ultimately graded and surely reflect significant instructor input. Such instructor input is generally important for the writing process and will mostly be maintained throughout the course. After some discussion amongst the physics faculty, it was decided that the final report that the students produce should only pass through a single draft, which will better reflect the student effort. This modification will equate to an improved test of the learning process and a greater efficiency for the faculty member, as the students will be forced to demonstrate acceptable writing without the use of the instructor. As a second example, *SLO #2 Use mathematical representations to analyze physical scenarios. (quantitative literacy)* is assessed at the beginning level in PHYS 132 – Electromagnetism and Optics, where the single vector addition problem is being replaced by a standardized two-problem vector addition quiz near the end of the semester. This modification will not only better assess the student learning objective but will additionally serve as a review for the final exam.

Probably the greater impact on teaching and learning through this program review process is more intangible and harder to directly measure than that mentioned in the previous paragraph. This review process has forced the physics faculty to reexamine every detail of our program with a critical eye with the intent of seeking out improvements for our program. This process has mostly confirmed to the faculty that we run a high-quality program, but new ideas have emerged for our program going forward. Additionally, our two newest tenure-track faculty members have both contributed to the writing and review of this document and have surely gained a broader perspective on the entirety of the physics program from this process.

d. Recommendations for Addressing Challenges

Having a diverse faculty can help cultivate an inclusive environment on a college campus and can aid in attracting and retaining students to the Physics Program from underrepresented groups. With the addition of Dr. Kim in the fall of 2019 and Dr. Whiting in the fall of 2020, the Physics Program has added needed diversity to our faculty. We hope that this increased diversity in faculty will yield an increased diversity in our physics majors. In regard to the lack of a dedicated classroom for our introductory physics courses, we recommend that PHYS 100 – Concepts of Physics be regularly scheduled in Wubben Hall 131. This course has traditionally been taught with the inclusion of many physics demonstrations throughout the semester and has suffered a loss in enrollment in recent years, which was discussed previously in Section 3. Having a dedicated classroom in Wubben Hall will allow for the installation of some permanent physics demonstrations. The hiring of a laboratory coordinator that could teach several of our physics lab courses would not only ease the burden of laboratory set up and tear down for our tenured and tenure-track faculty, but would also reduce our need in hiring adjunct instructors. Lastly, we recommend that the physics faculty be given administrative privileges on the computers in the physics laboratories in Wubben Hall 210, 214, 216, and 218.

Section 7: COVID Response 2021-22

The COVID-19 pandemic affected the Physics Program starting in March 2020. The most significant disruptions to the program operations were in delivery method of material in courses, especially laboratory courses. During the second half of the Spring 2020 semester, students were not allowed on campus and all academic operations were done remotely. During the Fall 2020 and Spring 2021 semesters, classes were conducted in-person but with reduced class size and hybrid formats (partly in-person, partly remote) for larger classes.

During the second half of the Spring 2020 semester, laboratory course material had to be delivered online. While there are occasionally freshman-level laboratory exercises that are conceptual in nature and that could still be offered in unaltered form, the bulk of laboratory exercises require equipment. This was most severe in the Advanced Laboratory course (PHYS 331), where the activities are not amenable to online conversion. Students in that course during that semester missed important learning experiences.

During the 2020-2021 academic year sophomore and the upper-division laboratory courses resumed normal operations. However, freshman-level laboratory courses operated with half the students meeting in person at any single time. The remaining half had to do an online laboratory activity. Again, there was some loss of learning experience in these courses. For example, students who were doing an online activity, that would normally require direction and assistance from an instructor, seldom attended online meetings and this affected the level of work that they turned in.

Delivery of lecture courses throughout this period was affected by distancing requirements that resulted in hybrid delivery for many freshman-level courses. This resulted in inefficiencies in student learning.

A less tangible affect was the loss of community for students. For example, normally students work in pairs in freshman-level laboratory courses, but this was impossible during the 2020-2021 academic year. Consequently, laboratory course meetings were much less interactive than usual, and students did not have the normal ways to connect with their peers and work together on their physics courses. The Physics Program encourages students to develop a community of peers, and this helps sustain students through the program. We are concerned that this loss will adversely affect retention in the subsequent years.

Appendix A

Physics Program Data, AY 2013-14 through AY 2019-20

Academic Year	FTES[1]	FTEF[2]	FTES:FTEF[3]
2013-2014	134.3	6.1	22.1
2014-2015	138.5	6.1	22.6
2015-2016	139.6	6.1	22.8
2016-2017	135.6	6.0	22.8
2017-2018	137.7	6.0	22.8
2018-2019	134.2	6.2	21.8
2019-2020	125.8	5.9	21.4

[1] Full-time equivalent students, equal to total student credit hours divided by 30 (the academic year full-time load for students)

[2] Full-time equivalent faculty, equal to total course credit hours divided by 24 (the academic year full-time load for faculty)

[3] Ratio of full-time equivalent students (FTES) to full-time equivalent faculty (FTEF)

Appendix B

Colorado Mesa University Faculty Evaluation
Western Colorado Community College Faculty Evaluation

CRN

0 0 0 0 0
1 1 1 1 1
2 2 2 2 2
3 3 3 3 3
4 4 4 4 4
5 5 5 5 5
6 6 6 6 6
7 7 7 7 7
8 8 8 8 8
9 9 9 9 9

Instructor Name: ______________________________ Course: ____________ (i.e. ENGL 111) Section # _______ (i.e. 001)

NOTE TO STUDENTS: Your responses are anonymous. The results will not be returned to the professor until AFTER grades have been posted. **IMPORTANT!** This document will be scanned for data entry. Please completely fill in the circle of your selection with pencil or a black or blue pen.

OPTIONAL DATA SECTION: Your responses to the following items are optional.

1. Gender
1 Male
2 Female

2. Classification
1 Freshman
2 Sophomore
3 Junior
4 Senior
5 Unclassified
6 Graduate

3. Type of Course
1 Essential Learning
2 Required for Major
3 Elective in Major
4 Elective Non Major

4. Degree
1 Certificate
2 Associate
3 Bachelor's
4 Post Baccalaureate Certificate
5 Master's
6 Doctorate
7 Undeclared
8 N/A

5. Department of Major
1 Art
2 Biological Sciences
3 Business
4 Computer Science, Math, & Statistics
5 Engineering
6 Health Sciences
7 Kinesiology
8 Languages, Literature, & Mass Comm.
9 Music
10 Physical & Environmental Sciences
11 Social & Behavioral Sciences
12 Teacher Education
13 Theatre Arts
14 WCCC
15 Undeclared

6. Expected grade for this course:
1 A
2 B
3 C
4 D
5 F
6 Don't Know

REQUIRED SECTION: Please answer each item as it applies to this class or to this professor, according to the following scale from strongly agree to strongly disagree, and not observed.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Not Applicable
The course assignments are clear.	1	2	3	4	5	6
The grading policies/procedures/criteria for this course are clear.	1	2	3	4	5	6
The teaching methods/techniques used by the professor are effective.	1	2	3	4	5	6
The exams and assignments of the course are consistent with the course content.	1	2	3	4	5	6
The course is appropriately challenging.	1	2	3	4	5	6
The course syllabus accurately reflects the learning outcomes.	1	2	3	4	5	6
The instructor is well prepared for class.	1	2	3	4	5	6
The instructor responds to student questions at an appropriate level.	1	2	3	4	5	6
The instructor uses a variety of teaching methods.	1	2	3	4	5	6
The instructor explains how material in the course is useful or relevant.	1	2	3	4	5	6
The instructor is accessible to students during office hours or by appointment.	1	2	3	4	5	6
The instructor promotes respect and civility for all students.	1	2	3	4	5	6

Please make comments on the back of this sheet.

Written Comments:

Please take the opportunity to make written comments about this class and the professor on this side of the evaluation sheet - in pencil. Such comments can be useful in helping the professors evaluate their teaching styles and effectiveness.

A. What were the most effective aspects of this course?

B. What changes would you recommend for this course?

C. Are the classroom/laboratory facilities conducive to learning? - If not, please explain.

D. Other Comments:

CMU Course Evaluation Form Revised Spring 2021

Thank you for taking the time to evaluate {CourseName}. Your responses are anonymous. The results will not be returned to the instructor until AFTER grades have been posted.

What is the purpose of this course in your program of study?

- ◯ Essential Learning Requirement
- ◯ Major Requirement
- ◯ Restricted Elective in Major
- ◯ Minor Requirement
- ◯ Restricted Elective in Minor
- ◯ Elective

Expected Grade in this Course

- ◯ A
- ◯ B
- ◯ C
- ◯ D
- ◯ F
- ◯ Don't Know

On average, how many hours per week do you put into this course including class time?

0 3 5 8 10 13 15 18 20 23 25

Hours

Please answer each item as it applies to {Course Name}, according to the following scale from strongly agree to strongly disagree, and not applicable.
The course assignments are clear to me.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Grading criteria are clear to me.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Course exams are consistent with course material (textbook, lectures, assignments, study guides, etc.).

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

I felt appropriately challenged by this course.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Course assignments help me learn material.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Please answer each item as it applies to Instructor {First Name} {Last Name}, according to the following scale from strongly agree to strongly disagree, and not applicable.
The teaching methods/techniques used by the professor are effective for me.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Instructor utilized technological resources effectively for my learning.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Instructor responds to student questions at an appropriate level for me.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Instructor explains how course materials and/or activities are useful or relevant.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Instructor responds to student communication in a timely way (in person or on-line)

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Instructor promotes respect and civility for all students.

○ Strongly Agree

○ Agree

○ Neither agree nor disagree

○ Disagree

○ Strongly disagree

○ Not Applicable

Please take the opportunity to make written comments about this course and Instructor {LastName}. Such comments can be useful in helping the instructors evaluate their teaching style and effectiveness.

What were the most effective aspects of this course?

____

____

What changes would you recommend for this course?

____

____

Appendix C

Library Program Assessment
John U. Tomlinson Library
Colorado Mesa University

Date of Assessment: October 2021

Program under review: Physics

Description of Program: Physics is the study of the universe: what it is made of and how it works, ranging from stars and galaxies to atoms and nuclei and everything in between. Physics forms the foundation of many technical fields including electronics and optics. Physics also features prominently in many of the hottest areas of current research and innovation, such as the multidisciplinary fields of nanotechnology and biophysics.

Program Level/s: Bachelors

Liaison: Jamie Walker

1. Collection Assessment

   The assessment covers five areas: Reference sources, Monographs, Electronic resources, Periodicals, and Media. The assessment methodology, supporting data and resource lists are included in the Appendices.

   Collection development is the joint responsibility of the Physics faculty and the Physics Librarian. Review slips are sent to the faculty each month for their review. They may also recommend titles found in their journal reading, publishers' advertisements, or other sources. Titles recommended are sent to the librarian, who reviews them and sends them on for purchase as funds allow. 160 titles were purchased in the last 5 years distributed per below.

FY 2016-2017	FY 2017-2018	FY 2018-2019	FY 2019-2020	FY 2020-2021
34	24	41	38	23

   The budget line is also supplemented by the SpringerLink, ScienceDirect (Elsevier), and Oxford e-book collections.

2. Evaluation of the total collection

a. Strengths

Journals, and books are important resources for physics faculty and majors. The indexing and full-text provided by CMU's database subscriptions provide access to much current scholarship in the field, strengthening the Library's resources for physics research. While not extensive, the Library's reference collection supports the need for authoritative concise information. The Library's e-book collection is strong in the sciences and physics is well represented. E-books on both general and esoteric topics are readily available. The Library's DVD, and Films on Demand collections provide useful resources, especially for general and introductory needs. The circulating physics book collection receives regular use and sufficiently supports coursework for undergraduate physics majors.

b. Weaknesses

As the physics monographic collection continues to be expanded, effort should be made to select materials that support less well represented or emerging subject areas, such as thermodynamics. If there is interest in media materials for more advanced students, additional materials could be purchased for this purpose.

3. Recommendations

The purchase of newer titles in physics should continue, and the current scope of electronic resources should be maintained.

Library Director:

Sylvia L. Rael

Date: October 19, 2021

A. Reference sources

The print reference collection provides concise authoritative information with 27 print titles on the general subject of physics. Additional support is provided by online resources.

Sample print and online Reference titles:

CRC handbook of chemistry and physics (print, 2020)
Dictionary of astronomy (online, 2018)
Dictionary of physics (print, 2000, and online, 2019)
Dictionary of pure and applied physics (print, 2001)
Dictionary of space exploration (online, 2018)
Dictionary of weights, measures, and units (online, 2002)
Encyclopedia of physics (print, 2004)
Encyclopedia of the solar system (print, 2007, online, 2014)

B. Monographs

Method of analysis: Broad terms were derived in consultation with department faculty. Each of these terms was searched in the library catalog by date range using the exact Library of Congress Subject Headings (LCSH). Results are below.

Age Analysis: For the print/media portion of the collection analyzed by subject in the charts below, 15% were published since 2010, with 32% published since 2000. For electronic materials, 72% were published since 2010, 91% since 2000. For the collection analyzed by classification number, in the entire QC collection, about 12% were published since 2010, with 29% since 2000. Print/Media includes physical print and media items in the collection. electronic materials include all online access materials such as government documents, streaming videos, e-books, or maps.

Physics	Print/ Media	Electronic
2010-	26	565
2000-2009	48	83
Pre 2000	155	67
TOTAL	229	715

Quantum Theory	Print/ Media	Electronic
2010-	39	380
2000-2009	45	128
Pre 2000	148	53
TOTAL	232	561

Electro-magnetism	Print/ Media	Electronic
2010-	4	56
2000-2009	2	13
Pre 2000	14	8
TOTAL	20	77

Dynamics	Print/ Media	Electronic
2010-	3	214
2000-2009	1	85
Pre 2000	22	15
TOTAL	26	314

Thermo-dynamics	Print/ Media	Electronic
2010-	20	210
2000-2009	14	63
Pre 2000	83	42
TOTAL	117	315

Statistical Thermodynamics	Print/ Media	Electronic
2010-	2	9
2000-2009	2	3
Pre 2000	8	2
TOTAL	12	14

Another way of analyzing the collection is by LC Classification Number range which examines primarily print books. Highlighted here are portions of the physics (QC) materials.

Call number ranges	QC Physics (all)	QC 1-75 General Physics	QC 170-197 Atomic Physics	QC 310.15-319 Thermo-dynamics	QC 669-675.8 Electro-magnetic theory	QC 770-798 Nuclear physics
2010-	273	35	89	8	0	16
2000-2009	395	100	110	8	1	26
Pre 2000	1653	377	347	36	11	153
TOTAL	2321	512	546	52	12	195

Recent physics monographic purchases:

- Banerjee, J. P., Banerjee, S., 2019, **Physics of semiconductors and nanostructures**: Boca Raton, CRC Press, 411 p.
- Gerig, A. L., 2021, **Introduction to wave physics**: U.S., The Author, 190 p.
- Helliwell, T. M., Sahakian, V. V., 2021, **Modern classical mechanics**: Cambridge, Cambridge University Press, 687 p.
- Lee, M., 2020, **Optics for materials scientists**: Palm Bay, Apple Academic Press, 371 p.
- Luscombe, J. H., 2021, **Statistical mechanics from thermodynamics to the renormalization group**: Boca Raton, CRC Press, 385 p.
- Mahamuni, S., Sidhaye, D., Kulkarni, S., 2021, **Foundations of experimental physics**: Boca Raton, CRC Press, 362 p.
- Mancini, S., Winter, A., 2021, **A quantum leap in information theory**: New Jersey, World Scientific, 231 p.
- Smith, W F., 2020, **Experimental physics principles and practice for the laboratory**: Boca Raton, CRC Press, 437 p.
- Suits, B. H., 2020, **Electronics for physicists, an introduction**: Cham, Springer, 331 p.
- Tilley, R. D., 2021, **Understanding solids the science of materials**: Chichester, John Wiley, 598 p.

As a partial government depository, the Library also makes available a large number of federal documents. For physics, included are those published by a variety of governmental agencies such as NASA. These are available in a variety of formats with most recent documents online.

C. Electronic Resources

Indexes/Databases: Two databases were selected for analysis.

Academic Search Complete: A general subject academic journal database that contains thousands of full-text peer reviewed journals including titles specific to physics. Coverage goes back to the late 1960s.

PROLA (Physical Review Online Archive): Full-text physics research journal articles from 1893 up to the most recent four years.

Journal Articles:

Subject searches for some of the topics to be covered in the courses for this program were done in Academic Search Complete (ASC) and PROLA databases to illustrate available resources. The journal literature is rich in articles for this program. The chart below shows a sampling of the resources available. For ASC, the larger figure on top is for a keyword within the subject index search, the smaller figure below reflects an exact subject term search. Results in italics were conducted as plain keyword searches not within the subject index.

Subject/Topic	ASC Total Articles	ASC 2010- Articles	ASC 2010- Peer reviewed	ASC 2010- Peer reviewed, full-text	PROLA Total Articles	PROLA 2010- Articles
Physics	578,230 47,398	331,322 9,995	282,146 8,200	200,532 5,057	114,342	114,399
Quantum Theory	69,937 30,609	39,213 30,609	31,881 25,180	20,895 16,751	697,656	233,243
Electro-magnetic fields	42,207 24,856	25,320 14,232	22,692 12,671	13,379 7,450	*64,124*	*38,761*
Dynamics	316,716 40,759	210,028 20,533	194.573 18,990	145,086 13,847	*208,210*	*120,882*
Thermodynamics	100,625 69,912	69,878 43,975	65,924 41,864	52,614 34,176	638	638
Statistical Thermodynamics	588 557	421 414	393 386	301 299	*1,659*	*656*

Other Databases

Other databases of possible interest include Science Direct and Wiley.

D. Periodicals

Many physics journal titles which formerly were held in print have moved to online access and are maintained through individual subscriptions, or are contained in science databases such as ScienceDirect (Elsevier), Wiley, or Academic Search Complete. The following titles highlight available journals and include some CMU former print titles now online.

Ad Astra = To the stars
American journal of physics
Astronomy
Entropy
European physical journal
International journal of heat & mass transfer
International journal of theoretical physics
Journal of electromagnetic waves & applications
Journal of experimental & theoretical physics
Journal of statistical physics
New journal of physics
Physica A
Physical review letters
Physics letters A, B
Physics teacher
Physics today
Reviews of modern physics
Sky and telescope
Thermodynamics

A search of the subject "physics" in our Journal Finder retrieved 345 full-text journal titles. CMU students and faculty have a large number of quality titles from which to choose.

E. Media

The Library holds physical DVDs and VHS, and also subscribes to Films on Demand (FoD), a streaming video service from Films Media Group. Films on Demand includes educational videos, documentaries, and PBS publications. Links to streaming media can be inserted into D2L to facilitate viewing. A subject search of the subjects used above in the library catalog brings up over 300 titles, most of which are available by streaming online. Most streaming materials are introductory or intermediate in nature, although some may be appropriate for more advanced students. Some titles that might be appropriate for this program are:

Breaking the wall of quantum weirdness: how experiments reveal photon schizophrenia (16 min., FoD, 2012)
Changing states of matter (26 min., FoD, 2006)
Friction, work, and energy (25 min., FoD, 2005)
Future of fusion (11 min. FoD, 2010)
Illusion of time (60 min., FoD, 2013)
Light, heat, and electricity (59 min., FoD, 2013)
Linear momentum and Newton’s laws of motion (24 min., FoD, 2005)
Microengineering and nanotechnology (17 min., FoD, 2006)
Mystery of light in quantum physics (41 min., FoD, 2012)
Nanotechnology introduction (26 min., FoD, 2009)
Physics and chemistry of water (21 min., DVD, 2000)

Physics in baseball (27 min., FoD, 2006)
Physics of amusement park rides (30 min., FoD, 2005)
Principles and laws of motion (29 min., FoD, 2009)
Principles of flight (59 min., FoD, 2007)
Properties of gases (23 min., DVD, 2006)
Quantum leap (60 min., FoD, 2013)
Special theory of relativity (63 min., FoD, 2007)
Thermodynamics (34 min., FoD, 2005)
Understanding scientific measurement (20 min., FoD, 2009)
What is physics (35 min., FoD, 2005)

F. Additional Resources

Journal literature not available through Colorado Mesa University, including those titles not available because of publisher embargo, can be provided by the Interlibrary Loan Department. The average amount of time it takes to fill an article request is 12 hours.

Physical items such as books and DVDs not owned by Colorado Mesa University can be borrowed from other libraries within the state or region through programs such as Prospector, and when necessary, throughout the world. Items from regional libraries typically arrive in 3-5 business days.

G. Research Instruction and Guidance

Librarians provide instruction on how to find, use, and cite materials. They can customize instruction for the specific topic at hand, including the intricacies of finding materials in a particular subject area. Sessions can be introductory or advanced in nature. Instruction can be provided in the regular classroom, in the library classroom, or remotely. Customized web materials can also be created to guide students to use and discover appropriate resources, which can be embedded in D2L.

Students may receive personal assistance from professional degreed librarians through the Research Help Desk. The desk is staffed most hours the library is open. Help is available in-person, via telephone, email, and 24/7 chat.

Appendix D

Student Learning Objectives

1) Show fluency with the major fields of physics (classical mechanics, electromagnetism, statistical physics and quantum theory). (**Specialized knowledge/applied learning**)
2) Use mathematical representations to analyze physical scenarios. (**Quantitative literacy**)
3) Use laboratory techniques to investigate experimentally physical phenomena. (**Specialized knowledge/applied learning**)
4) Communicate effectively about topics in physics. (**Communication fluency**)
5) Execute a project which addresses a significant and complex issue in physics. This project will integrate knowledge and techniques from different areas of physics. (**Critical thinking**)
6) Reflect on ethical, social and civic issues in physics. (**Personal and social responsibility**)
7) Find information relevant to physics, evaluate this critically and apply the information. (**Information literacy**)

BS Physics Degree Curriculum Map

Outcome	**1**	**2**	**3**	**4**	**5**	**6**	**7**
PHYS 131	x	x					
PHYS 131L	x		x	x			
PHYS 132	x	x					
PHYS 132L	x		x	x			
PHYS 230	x	x					
PHYS 231	x	x				x	
PHYS 251	x	x	x				
PHYS 252	x		x	x			x
PHYS 311	x	x					
PHYS 312	x	x					
PHYS 321	x	x					
PHYS 331			x	x		x	x
PHYS 342	x	x					
PHYS 362	x	x					

PHYS 372	x	x					
PHYS 396	x	x					
PHYS 422	x	x					
PHYS 471	x	x					
PHYS 473	x	x					
PHYS 482					x		
PHYS 494				x			

Appendix E: **COLORADO MESA UNIVERSITY**

New Assessment Plan (Each Outcome: Sections 1 - 4 Only)

Annual Report (Each Outcome: All 6 Sections)

Three and Six-Year Summary Assessment Report (Each Outcome: All 6 Sections)

(Revised Spring 2019)

Program Name: Physics

Date of Submission: 9/24/2021

1. In the area provided below and in reverse chronological order, please present a timeline of when the program faculty reviewed the program assessment plan and/or report.

Please focus on dates when the following were performed:

A) The learning outcomes were reviewed by the program faculty for possible revision.
(New Assessment Plans can omit B, C, and D)
B) All program faculty received the assessment results.
C) Faculty input regarding the results was sought.
D) The majority of program faculty met face-to-face to discuss the assessment results in depth.

June/July 2021 A) Outcomes and methods of assessment were reviewed on July 20, 2021. Possible revisions were proposed during the same meeting.
B) Faculty input on data solicited.
C) Assessment data for the period from Fall 2013 to Spring 2021 provided to faculty.
D) Faculty met on July 20, 2021 to discuss the data and assessment plan.

2. Two Assessment Highlights (only necessary for 3- and 6-year summary reports)

- Highlight 1: We have used information from students' work and assessments to continuously clarify goals for and to improve student work in both the Senior Seminar (Phys 494) and Senior Research (Phys 482). Most physics faculty members are aware of the research that all students produce in these courses and we have often discussed specific student work informally. It is our opinion that the quality of this work has improved substantially since 2013 (when the assessment program commenced). Evidence for this appears in the detailed discussions of Outcomes 4 and 5.
- Highlight 2: We have also used information from students' work and assessments to continuously clarify goals and improve student writing in the Senior Research and laboratory courses. Those physics faculty who reviewed student writing from these courses also believe that the quality of student writing has improved substantially since 2013 (when the assessment program commenced). This improvement has likely resulted from identification of particular deficiencies and subsequently addressing those in later rubrics. Over time the more recently addressed deficiencies have become more minor, indicating that the core aspects of the writing have improved. Evidence for this appears in the detailed discussions of Outcomes 3 and 4.

The assessment process has assisted in improving some student learning outcomes. For others the existing process has probably not revealed useful information. The immediate action will be to revise the assessment process for those outcomes so that it yields more robust information. Proposed revisions of outcomes are described in Section 6 under each learning outcome.

COLORADO MESA UNIVERSITY

New Assessment Plan (Each Outcome: Sections 1 - 4 Only)
Annual Report (Each Outcome: All 6 Sections)
Three and Six-Year Summary Assessment Report (Each Outcome: All 6 Sections)
(Revised Spring 2019)

Please attach the last three years of annual departmental assessment activity, the curriculum map, and any department/program minutes that recorded discussion of learning outcomes. Summarize each student-learning outcome that has been assessed over the past three/six years. Attach rubrics used in assessment.

Assessment Summary for Program Outcome 1

Program Outcome 1 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Show fluency with the major fields of physics (classical mechanics, electromagnetism, statistical physics and quantum theory). (Specialized Knowledge)	**PHYS 131 Fundamental Mechanics (B)**	**What:** Force Concept Inventory exam. **How:** Delivered at the beginning and end of the semester to test the student's understanding of forces, momentum, and energy.	**Who:** All instructors of PHYS 131 **When:** Beginning and end of semester
	PHYS 321 Quantum Theory (A)	**What:** Quantum Mechanics Assessment Tool QMAT **How:** Delivered at the beginning and end of the semester to test the student's understanding of quantum physics quantitatively and qualitatively.	**Who:** Instructor of PHYS 321 **When:** Beginning and end of semester

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results: Force Concept Inventory (Phys 131)

The following are the normalized gains for each section Phys 131 that were offered each semester. No data was available for the Spring 2020 and Fall 2020 semesters due to the interruption from COVID.
Each student takes the test twice; once at the beginning of the semester (pre) and another time at the end of the semester (post). The normalized gain for an individual student is determined via: (post score – pre score)/ (max possible score – pre score).

Semester	Section 1 Average normalized gain	Section 1 Population	Section 2 Average normalized gain	Section 2 Population
2021 Spring	0.27	33	0.33	20
2019 Fall	0.42	26	0.46	19
2019 Spring	0.48	82	Combined with section 1	
2018 Fall	0.46	22	0.54	40
2018 Spring	0.41	32	0.45	30
2017 Fall	0.50	25	0.57	30
2017 Spring	0.35		0.44	66 both sections
2016 Fall	0.29	30	0.44	24
2016 Spring	0.44		No section 2 offered	
2015 Fall	0.48	30	0.35	30
2014 Fall	0.48	27	0.46	32
2013 Fall	0.53	35	0.43	35

Key findings: Force Concept Inventory (Phys 131) Data shows averages typically in the region of 0.40 to 0.50 with occasional fluctuations. The most recent semester indicates a dip in the data.

Analysis: Force Concept Inventory (Phys 131) The program benchmark has been an average normalized gain of 0.25. The FCI consists of 30 conceptual physics questions and has been extensively administered and studied at institutions in the United States. A high-gain course will produce average normalized gains greater than 0.70 and a medium-gain course in the range 0.30 to 0.70. Generally, Phys 131 has yielded results roughly in the middle of the medium gain region.
Research indicates that courses that involve interactive engagement techniques typically outperform traditional passive learning methods. Interactive engagement techniques have been used in most sections of Phys 131 and appear to bear fruit. Most of our faculty have learned these techniques via an annual workshop run by the American Association of Physics Teachers; the focus of this workshop is to move physics instruction away from passive delivery into more active delivery with techniques emanating from Physics Education Research.

Results: Quantum Theory (Phys 321)
It appears that the QMAT test has not been used and, in its place a single question from a class exam that involves the normalization of a wave-function and finding its probability density and expectation values of its observables. The average score for all students in the single section of this course is provided below.

Semester	Average Score (Percent)	Population
2021 Spring	71	7
2020 Spring	79	9
2017 Spring	81	N/A
2015 Fall	79	6
2014 Fall	80	2
2013 Fall	70	8

Key findings: Quantum Theory (Phys 321) Data shows averages typically in the region of 70% to 80%.

Analysis: Quantum Theory (Phys 321) The data only reflects performance on a single exam question that covers a limited portion of quantum theory. This limits its utility.

Actions Taken (Include any budget implications.) (Section 6)

Action: Force Concept Inventory (Phys 131) We will continue monitoring conceptual learning via FCI results. We will continue to develop and use interactive learning strategies, such as think-pair-share quizzes and in-class group activities, that enhance the type of learning that this tests.

The normalized gain benchmark will be shifted to 0.35. Instructors will gather data for each individual FCI question and, if this reveals areas where the learning is deficient, those areas will be targeted in subsequent offerings of Phys 131.

Action: Quantum Theory (Phys 321) No modifications to the course.

The current single question will be replaced by students taking the Quantum Mechanics Concept Assessment (QCMA). This will be administered at the end of the semester in which students take Phys 321. The benchmark will be that the class average is at least 50% but this may be adjusted in future semester. Results from individual questions will be used to strengthen instruction and assignments in the relevant sections of Phys 231 and Phys 321.

Re-evaluation Date: January 2022

Assessment Summary for Program Outcome 2

Program Outcome 2 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Use mathematical representations to analyze physical scenarios. (Quantitative Literacy)	**PHYS 132 Electromagnetism and Optics (B)**	**What:** A vector-based problem that includes electric and magnetic forces/fields and/or potentials **How:** Delivered as a problem on the midterm exam.	**Who:** All instructors of PHYS 132 **When:** On a midterm examination
	PHYS 311 Electromagnetic Theory (A)	**What:** A vector calculus-based problem that includes electric and magnetic fields and/or potentials as well as applications of Maxwell's equations. **How:** Delivered as a problem on the midterm exam.	**Who:** Instructor of PHYS 311 **When:** On a midterm examination

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results: Electromagnetism and Optics (Phys 132)

The average score for all students in the single section of this course is provided below.

Semester	Average Score (Percent)	Population
2021 Spring	77	39
2020 Fall	82	37
2020 Spring	80	30
2019 Fall	71	40
2018 Fall	71	45
2017 Fall	83	44
2017 Spring	81	39
2016 Fall	65	36
2016 Spring	65	36
2015 Fall	77	27
2015 Spring	70 and 78 (two sections)	69 (two sections)

Key findings: Electromagnetism and Optics (Phys 132) Data shows averages typically in the region of 65% to 83% with some improvement since 2016.

Analysis: Electromagnetism and Optics (Phys 132) The stated benchmark was 70% and this was attained in most semesters. The data does only reflect performance on a single question, and this question has varied from one semester to another.

Results: Electromagnetic Theory (Phys 311)

The average score for all students in the single section of this course is provided below.

Semester	Average Score (Percent)	Population
2020 Fall	84	9
2019 Fall	64	6
2018 Fall	86	6
2017 Fall	63	7
2015 Fall	66	5
2014 Fall	75	6
2013 Fall	79	8

Key findings: Electromagnetic Theory (Phys 311) Results have fluctuated in the range of 63% to 86%.

Analysis: Electromagnetic Theory (Phys 311) The stated benchmark was 70% and this was attained four out of the seven instances. Data will be subject to substantial fluctuations resulting from the small population size. The data does only reflect performance on a single question, and this question has varied from one semester to another.

Actions Taken (Include any budget implications.) (Section 6)

Action: Electromagnetism and Optics (Phys 132) Continued monitoring of performance on such vector addition problems.

The current single question will be replaced by a standardized exam consisting of at least two questions. This exam will be administered at the end of the semester. The initial benchmark will be that the average score on the exam will be 70%.

Action: Electromagnetic Theory (Phys 311) No change to the course.

The current single question will be replaced by a standardized exam consisting of at least two questions. This exam will be administered at the end of the semester. The initial benchmark will be that the average score on the exam will be 70%.
Re-evaluation Date: January 2022

Assessment Summary for Program Outcome 3

Program Outcome 3 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Use laboratory techniques to investigate experimentally physical phenomena. (Specialized Knowledge)	**PHYS 251 Electronics for Scientists (B)**	**What:** In PHYS 251, laboratory exercises that require use of lab equipment. **How:** In PHYS 251 students do (and report on) exercises involving laboratory equipment use. These exercises are graded and one will be selected.	**Who:** Instructor of PHYS 251. **When:** During the semester when this course is offered.
	PHYS 331 Advanced Laboratory (A)	**What:** In PHYS 331, a journal-style laboratory report describing an experimental physics project. **How:** In PHYS 331, the report will be graded partly on consideration of the scientific level of difficult, completeness and correctness.	**Who**: Instructor of PHYS 331. **When**: During the semester when this course is offered.

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results: Electronics for Scientists (Phys 251)

The average score for all students in the single section of this course is provided below.

Semester	Average Score (Percent)	Population
2019 Fall	95	12
2018 Fall	90	4
2017 Fall	87	6
2016 Fall	88	9
2015 Fall	88	8
2014 Fall	75	5
2013 Fall	75	8

Key findings: The average score on the exercise was always greater than 75%.

Analysis: The benchmark for this outcome is 70%. The course has routinely exceeded this benchmark. It appears that the scores were obtained by grading a single lab journal entry. These scores could have partly reflected how well the students communicate rather than their ability to use laboratory techniques, although that would have contributed to the scores.

Results: Advanced Laboratory (Phys 331)

The average score for all students in the single section of this course is provided below.

Semester	Average Score (Percent)	Population
2021 Spring	92	7
2020 Spring	90	4
2019 Spring	89	5
2018 Spring	87	6
2015 Fall	87	8
2014 Fall	65	8
2013 Fall	82.5	5

Key findings: The average score on the exercise was, with one exception, always greater than 75%.

Analysis: The benchmark for this outcome is 70%. The course has routinely exceeded this benchmark. It appears that the scores have reflected the writing component of the report although they have included the laboratory techniques and analysis components.

Actions Taken (Include any budget implications.) (Section 6)

Action: Electronics for Scientists (Phys 251) No substantial course modification.

The assessment tool will be replaced with one that tests a particular experimental procedure that identifies properties of hidden ``mystery'' electronic circuit elements. This will be implemented as an exercise that will be graded by the instructor according to a rubric that assess the accuracy of identification and the clarity of the method used. This will eliminate the inclusion of the communication aspect in scores.

Action: Advanced Laboratory (Phys 331) No substantial course modification.

The rubric for grading the reports will contain a separate category that assess the scientific, technical and experimental content. The score from this category will be reported. The benchmark will be adjusted upward.

Re-evaluation Date: January 2022

Assessment Summary for Program Outcome 4

Program Outcome 4 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Communicate effectively about topics in physics. (Communication Fluency)	**PHYS 252 Intermediate Laboratory (B)**	**What:** In PHYS 252, journal style laboratory reports. **How:** One report will be graded using a rubric covering the following categories: i) scientific correctness and completeness, ii) formatting and iii) language/writing style.	**Who:** Instructor of PHYS 252. **When:** During the semester when the course is offered.
	PHYS 494 Senior Seminar (A)	**What:** Fifty-minute oral presentation (second time student takes PHYS 494). **How:** Students will be assessed by all faculty in attendance using a rubric covering the following areas, each graded on a scale of 1-5: i) scientific depth and correctness of presentation, ii) ability to communicate physical and mathematical concepts, and iii) student demeanor and professionalism of presentation.	**Who:** Instructor of PHYS 494. **When:** During the semester when the course is offered.

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results: Intermediate Laboratory (Phys 252)

The following table provides the average percentage score for the entire class for each rubric category.

Semester	Category i)	Category ii)	Category iii)	Population
2021 Spring	79	95	83	4
2020 Spring	93	85	88	8
2019 Spring	92	82	92	3
2018 Spring	88	80	82	8
2017 Spring	85	85	94	10
2016 Spring	91	93	78	
2015 Spring	92	91	88	6
2014 Spring	80	88	72	4

Key findings: Average percentage scores for the class were most frequently in the range of 80 – 95%.

Analysis: The benchmark for this outcome is 70%. The course has always exceeded this benchmark. The data shows that students are typically writing according to expectations. However, the data is obtained from final drafts of reports and these

used significant instructor recommendations and input from earlier drafts.
The rubrics for assessing student report writing has evolved frequently during the six-year period. Generally, these have become increasingly detailed and focused. The modifications were based on review of writing in previous semesters. Updated rubrics have been communicated to students and the grading and feedback has become more and more targeted toward specific issues encountered in the writing. The writing that we have seen in recent years has reached a standard where there are generally few organizational issues and what remains to be addressed are relatively minor stylistic and grammar issues.

Results: Physics Seminar (Phys 494)

The following table provides the average percentage score for the entire class for each rubric category. The data only reflects those semesters where there was at least one student who did the presentation for the second time. In many semesters the scores for each rubric category had not been collected; in these cases, the overall average score is collected in the category iii) column.

Semester	Category i)	Category ii)	Category iii)	Population
2021 Spring	91	89	93	7
2020 Fall	88	86	84	2
2020 Spring	91	91	94	3
2019 Fall	83	78	75	1
2019 Spring	92	94	94	5
2017 Spring			85	2
2016 Spring			83	3
2015 Fall			90	10
2014 Spring			90	2

Key findings: The overall scores always averaged above 80%.

Analysis: The benchmark for this outcome is 90%. The benchmark has been met roughly half the time, with several instances where the average score is close to the benchmark.
The preparation of the student seminars has been enhanced, with more practice sessions and targeted feedback. This is based on assessment of student performance in previous semesters.

Actions Taken (Include any budget implications.) (Section 6)

Action: Intermediate Laboratory (Phys 252) No substantial course modifications.

The assessment will be modified so that it considers the final lab report of the semester. This lab report will consist of a single draft with no intermediate instructor feedback and will better reflect independent student learning.

Action: Physics Seminar (Phys 494) No substantial course modifications.

Ensure that data is collected correctly.

Re-evaluation Date: May 2022

Assessment Summary for Program Outcome 5

Program Outcome 5 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Execute a project which addresses a significant and complex issue in physics, integrating knowledge and techniques from different areas of physics. (Critical Thinking)	**PHYS 482: Senior Research (A)**	**What:** Report on the senior research project written in the style of a scientific journal article. **How:** The scientific complexity, conceptual level, correctness of the project and the effort involved in executing the project ("project content") will be assessed using a rubric that considers the work presented in the final report and the weekly meetings. This assessment will not consider aspects of the final report related to presentation and writing. Separately the final report will be assessed for presentation and writing using a rubric which evaluates three categories: i) formatting (abstract, sectioning, figures and citations), ii) logical structure of the report and iii) language and writing style.	**Who:** Instructor of PHYS 482. **When:** After each student has completed their second semester of PHYS 482 (physics majors are required to take PHYS 482 twice; most complete their second semester in the Spring and some in the Fall).

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results:

The following table provides the percentage of students who attained at least 80% for the indicated rubric category. The "Content" column provides data for the "project content" category of the rubric.

Semester	Content	Category i)	Category ii)	Category iii)	Population
2021 Spring	100	100	100	83	6
2020 Fall	50	100	100	100	2
2020 Spring	100	100	100	100	3
2019 Fall	100	100	100	100	1
2019 Spring	92	95	95	94	6
2018 Fall	100	99	99	94	5
2018 Spring	95	91	91	89	4
2017 Fall	88	92	92	86	4
2016 Fall	100	100	100	100	1
2016 Spring	100	100	100	33	3
2015 Fall	0	0	0	100	1

2015 Spring	86	100	86	71	7
2014 Fall	100	100	100	100	1
2014 Spring	100	100	100	100	2

Key findings: The benchmark for each category is that at least 75% of students attain 80% in that category. This has mostly been attained. It should be noted that in semesters where there are one or two students who are evaluated, it is not unexpected to attain scores of 0% (no students attained the 80% level) or 50% (one student attained the 80% level).

Analysis: The data for the content category shows that most projects are of an appropriate level of conceptual complexity and difficulty and that most students do sufficient work on these projects. This reflects the fact that faculty carefully vet proposed projects and that the instructors generally maintain adequate levels of productivity from students.

The data for the writing categories indicate that by the time the final draft of the report has been assessed the formatting (category i) and structure (category ii) of the report are usually adequate. Again, this probably reflects the level of scrutiny that is applied to the drafts of this final report (in most cases there will effectively be about five drafts before the final report is submitted). The data indicates slightly more deficiencies with the language and writing style (category iii) of the report, which likely reflects that the instructors place greater emphasis on the two other categories.

The criteria for successful writing and the associated rubrics have evolved repeatedly during the six-year period. This has been guided by assessing writing in previous semesters, identifying deficiencies, addressing these in future aspects of the writing, including then in rubrics and communicating these to students via feedback and grades on intermediate parts of the course. Examples of deficiencies that we have addressed include omission or misplacement of major concepts in the work or using a chronological narrative that includes descriptions of failed attempts at answering the research questions. Rubrics were modified to address these and these issues are now caught in initial drafts of writing.

Actions Taken (Include any budget implications.) (Section 6)

Action: Proposed Action: In the future the data will be processed to provide the average score for the entire class for each of the rubric categories. The aim is to reveal better information in semesters when the number of students is small and to better assess whether students are scoring significantly more or less than the benchmark in the categories. The benchmark for each category will be adjusted to 85%.

The data reported in the future will focus on the previous content category and this will eliminate the communication aspects of the report from the assessment of this learning outcome. Additional components will be added to assessment rubrics to determine student understanding of the project.

Re-evaluation Date: May 2022

Assessment Summary for Program Outcome 6

Program Outcome 6 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Reflect on ethical, social and civic issues in physics. (Personal and Social Responsibility)	**PHYS 231 Modern Physics (B)**	**What:** In Phys 231, a written assignment in which students analyze the ethical and social implications of a modern physics development. **How:** The assignment will be graded according to a rubric in which the student i) identifies the social and or ethical context of the particular physics development, and ii) analyzes the social and ethical implications of the development.	**Who:** Instructor of PHYS 231. **When:** During the semester when the course is offered.
	PHYS 331 Advanced Laboratory (A)	**What:** In PHYS 331, students will produce a written assignment that analyses instances of scientific misconduct in physics. **How:** The assignment will be assessed using a rubric in which the student i) identifies the laboratory experiment and context of the misconduct and ii) analyzes the implications of this.	**Who:** Instructor of PHYS 331. **When:** During the semester when the course is offered.

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results: Modern Physics (Phys 231)

The following table provides the average score for all students in the single section of this course.

Semester	Average Score (Percent)	Population
2021 Spring	100	6

Key findings: This outcome was added in the Fall 2020 semester and first tested in the Spring 2021 semester. The class average was 100%.

Analysis: This content and assessment was included on a trial basis as a single exercise offered for extra credit during the COVID-related online week at the end of the semester. Roughly half the students participated. Those who did clearly took the exercise seriously. It is possible that the exercise was too formulaic or conceptually too simple to test students understanding of the complexities of ethical, social and civic issues in physics.
The trail indicated that it was feasible to include such content in the course in the future.

Results: Advanced Laboratory (Phys 331)

The following table provides the average score for all students in the single section of this course.

Semester	Average Score (Percent)	Population
2021 Spring	100	7

Key findings: This outcome was added in the Fall 2020 semester and first tested in the Spring 2021 semester. The class average was 100%.

Analysis: This content and assessment was included on a trial basis as a single writing exercise offered at the end of the semester. Grading was done on a credit/no-credit basis. The reported score reflects this. The trail indicated that it was feasible to include such content in the course in the future.

Actions Taken (Include any budget implications.) (Section 6)

Action: Modern Physics (Phys 231) In the future more than one such exercise will be offered during the semester, and it will be included in the course as part of the regular credit. The conceptual level of the exercise will be augmented, and the resulting student performance will be monitored so as to eventually reach a level which challenges the students appropriately.

Action: Advanced Laboratory (Phys 331) Such exercises will continue to be offered in the future.

Re-evaluation Date: May 2022

Assessment Summary for Program Outcome 7

Program Outcome 7 (Section 1)	Courses/Educational Strategies Used (Section 2)	Assessment Method(s) (Section 3)	Semester of Data Collection (Section 4)
Find information relevant to physics, evaluate this critically and apply the information. (Information Literacy)	**PHYS 252 Intermediate Laboratory (B)**	**What:** In PHYS 252, literature searches in scientific journals. **How:** For each of a set of laboratory exercises, students will find one journal article related to that exercise. Students will explain how the article relates to and informs the laboratory exercise as part of formal laboratory reports.	**Who:** Instructor of PHYS 252. **When:** Regularly during the semester when the course is offered.
	PHYS 331 Advanced Laboratory (A)	**What:** In PHYS 331, literature searches in scientific journals. **How:** For each of a set of laboratory exercises, students will find one journal article related to that exercise. Students will explain how the article relates to and informs the laboratory exercise as part of formal laboratory reports.	**Who:** Instructor of PHYS 331. **When:** Regularly during the semester when the course is offered.

Results and Analysis (include numbers of students involved in assessment and the percentage. Include any budget implications, and include year when applicable) (Section 5)

Results: Intermediate Laboratory (Phys 252)

The following table provides the average score for all students in the single section of this course.

Semester	Average Score (Percent)	Population
2021 Spring	82	4

Key findings: This outcome was added in the Fall 2020 semester and first tested in the Spring 2021 semester. The class average was 82%.

Analysis: The benchmark was 80%. The data indicates that the benchmark was met.

Results: Advanced Laboratory (Phys 331)

The following table provides the average score for all students in the single section of this course.

Semester	Average Score (Percent)	Population
2021 Spring	92	7

Key findings: This outcome was added in the Fall 2020 semester and first tested in the Spring 2021 semester. The class average was 92%.

Analysis: The benchmark was 80%. The data, however, likely includes other components of the laboratory report grades such as those reflecting writing, data management or clear descriptions of procedures; these are not what this rubric aims to assess.

Actions Taken (Include any budget implications.) (Section 6)

Action: Intermediate Laboratory (Phys 252) No immediate action.

Action: Advanced Laboratory (Phys 331) No course modification.

In the future this assessment outcome will be moved to Phys 482 (Senior Research).

Re-evaluation Date: May 2022

Attachment: BS in Physics Program-Level Student Learning Objectives/Curriculum Map

The institutional Student Learning Outcomes are as follows. The CMU baccalaureate degree graduate will be able to:

1) Construct a summative project, paper or practiced-based performance that draws on current research, scholarship and/or techniques, and specialized knowledge in the discipline **(specialized knowledge/applied learning)**;
2) Analyze data critically, reason logically, and apply quantitative analysis methods correctly to develop appropriate conclusions **(quantitative fluency)**;
3) Make and defend assertions about a specialized topic in an extended well-organized document and an oral presentation that is appropriate to the discipline **(communication fluency)**;
4) Describe reasoned conclusions that articulate the implications and consequences for a particular decision by synthesizing information and methodologies **(critical thinking)**;
5) Reflect on and respond to ethical, social, civic, and/or environmental challenges at local, national, and/or global levels **(personal and social responsibility)**; and
6) Find relevant sources of information, evaluate information critically, and apply the information appropriately and effectively to specific purposes **(information literacy).**

A student who completes the BS in Physics will have demonstrated the ability to:

8) Show fluency with the major fields of physics (classical mechanics, electromagnetism, statistical physics and quantum theory) (**Specialized knowledge/applied learning**);
9) Use mathematical representations to analyze physical scenarios (**Quantitative literacy**);
10) Use laboratory techniques to investigate experimentally physical phenomena (**Specialized knowledge/applied learning**);
11) Communicate effectively about topics in physics (**Communication fluency**);
12) Execute a project which addresses a significant and complex issue in physics. This project will integrate knowledge and techniques from different areas of physics (**Critical thinking**);
13) Reflect on ethical, social and civic issues in physics (**Personal and social responsibility**); and
14) Find information relevant to physics, evaluate this critically and apply the information (**Information literacy**).

BS Physics Degree Matrix

Outcome	1	2	3	4	5	6	7
PHYS 131	x	x					
PHYS 131L	x		x	x			
PHYS 132	x	x					
PHYS 132L	x		x	x			
PHYS 230	x	x					
PHYS 231	x	x				x	
PHYS 251	x	x	x				
PHYS 252	x		x	x			x
PHYS 311	x	x					
PHYS 312	x	x					
PHYS 321	x	x					
PHYS 331			x	x		x	x
PHYS 342	x	x					
PHYS 362	x	x					
PHYS 372	x	x					
PHYS 396	x	x					
PHYS 422	x	x					
PHYS 471	x	x					
PHYS 473	x	x					
PHYS 482					x		
PHYS 494				x			

Appendix F

CMU Alumni Survey Results
Comparison of physics alumni (PHYS) to all CMU alumni (CMU) for AY 2013-14 through AY 2019-20

Overall, how satisfied are you with your undergraduate education?

	PHYS		CMU	
	#	%	#	%
Very Satisfied	10	52.6%	354	44.8%
Generally Satisfied	9	47.4%	368	46.6%
Ambivalent	0	0.0%	43	5.4%
Generally Dissatisfied	0	0.0%	19	2.4%
Very Dissatisfied	0	0.0%	6	0.8%

While an undergraduate, about how often did you have conversations with faculty outside of class?

	PHYS		CMU	
	#	%	#	%
Never	0	0.0%	24	3.0%
Rarely (1-2 times per semester)	0	0.0%	98	12.4%
Occasionally (3-5 times per semester)	3	15.8%	188	23.7%
Often (once every two weeks)	1	5.3%	180	22.7%
Very Often (at least once a week)	15	78.9%	303	38.2%

Would you encourage a current high school senior to attend CMU?

	PHYS		CMU	
	#	%	#	%
Definitely Would	11	57.9%	476	60.0%
Probably Would	6	31.6%	216	27.2%
Maybe	2	10.5%	77	9.7%
Probably Would Not	0	0.0%	13	1.6%
Definitely Would Not	0	0.0%	11	1.4%

What degree(s) did you receive in Physics?

	#	%
A.S. Physics	2	10.5%
B.S. Physics	17	89.5%

In what year did you graduate from the major/certificate you chose above?

	#	%
2020	3	15.8%
2019	4	21.1%
2018	2	10.5%
2017	2	10.5%
2016	1	5.3%
2015	4	21.1%
2014	2	10.5%
2013	1	5.3%

How would you rate the overall quality of your education within that degree/certificate program?

	PHYS		CMU	
	#	%	#	%
Very High	9	47.4%	289	36.3%
High	10	52.6%	347	43.6%
Average	0	0.0%	137	17.2%
Low	0	0.0%	18	2.3%
Very Low	0	0.0%	5	0.6%

Associate Student Learning Outcomes

Based on what you know now, how well do you think your undergraduate experience prepared you to:

	PHYS									
	Very Well		More than Adequately		Adequately		Less Than Adequately		Very Poorly	
	#	%	#	%	#	%	#	%	#	%
Locate, gather and organize evidence on an assigned topic addressing a course or discipline-related question or a question of practice in a work or community setting (Specialized Knowledge/Applied Learning)	1	50.0%	1	50.0%	0	0.0%	0	0.0%	0	0.0%
Use program-level mathematical concepts and methods to understand, analyze, and explain issues in quantitative terms (Intellectual Skills: Quantitative Fluency)	1	50.0%	1	50.0%	0	0.0%	0	0.0%	0	0.0%

Make and defend claims in a well-organized, professional document and/or oral presentation that is appropriate for a specific audience (Intellectual Skills: Communication Fluency)	1	50.0%	1	50.0%	0	0.0%	0	0.0%	0	0.0%
Identify and gather the information/data relevant to the essential question, issue and/or problem and develop informed conclusions (Intellectual Skills: Critical Thinking)	1	50.0%	1	50.0%	0	0.0%	0	0.0%	0	0.0%
Reflect on and respond to ethical, social, civic, and/or environmental challenges at local, national, and/or global levels (personal and social responsibility)	1	50.0%	1	50.0%	0	0.0%	0	0.0%	0	0.0%
Identify, utilize and cite various sources of information in academic assignments, projects or performances (information literacy)	1	50.0%	1	50.0%	0	0.0%	0	0.0%	0	0.0%

Associate Student Learning Outcomes

Based on what you know now, how well do you think your undergraduate experience prepared you to:

	CMU									
	Very Well		More than Adequately		Adequately		Less Than Adequately		Very Poorly	
	#	%	#	%	#	%	#	%	#	%
Locate, gather and organize evidence on an assigned topic addressing a course or discipline-related question or a question of practice in a work or community setting (Specialized Knowledge/Applied Learning)	8	25.8%	10	32.3%	13	41.9%	0	0.0%	0	0.0%
Use program-level mathematical concepts and methods to understand, analyze, and explain issues in quantitative terms (Intellectual Skills: Quantitative Fluency)	6	19.4%	12	38.7%	13	41.9%	0	0.0%	0	0.0%
Make and defend claims in a well-organized, professional document and/or oral presentation that is appropriate for a specific audience (Intellectual Skills: Communication Fluency)	6	20.0%	14	46.7%	10	33.3%	0	0.0%	0	0.0%
Identify and gather the information/data relevant to the essential question, issue and/or problem and develop informed conclusions (Intellectual Skills: Critical Thinking)	12	40.0%	11	36.7%	7	23.3%	0	0.0%	0	0.0%

Baccalaureate Student Learning Outcomes

Based on what you know now, how well do you think your undergraduate experience prepared you to:

	PHYS									
	Very Well		More than Adequately		Adequately		Less Than Adequately		Very Poorly	
	#	%	#	%	#	%	#	%	#	%
Construct a summative project, paper or practiced-based performance that draws on current research, scholarship and/or techniques, and specialized knowledge in the discipline (Applied Learning/ Specialized Knowledge)	8	47.1%	4	23.5%	5	29.4%	0	0.0%	0	0.0%
Analyze data critically, reason logically, and apply quantitative analysis methods correctly to develop appropriate conclusions (Intellectual Skills: Quantitative Fluency)	10	58.8%	5	29.4%	1	5.9%	1	5.9%	0	0.0%
Make and defend assertions about a specialized topic in an extended well-organized document and an oral presentation that is appropriate to the discipline (Intellectual Skills: Communication Fluency)	9	52.9%	6	35.3%	2	11.8%	0	0.0%	0	0.0%
Describe reasoned conclusions that articulate the implications and consequences for a particular decision by synthesizing information and methodologies (critical thinking)	11	64.7%	4	23.5%	2	11.8%	0	0.0%	0	0.0%

Reflect on and respond to ethical, social, civic, and/or environmental challenges at local, national, and/or global levels (personal and social responsibility)	5	29.4%	2	11.8%	7	41.2%	3	17.6%	0	0.0%
Find relevant sources of information, evaluate information critically, and apply the information appropriately and effectively to specific purposes (information literacy)	8	47.1%	8	47.1%	1	5.9%	0	0.0%	0	0.0%

Baccalaureate Student Learning Outcomes

Based on what you know now, how well do you think your undergraduate experience prepared you to:

	CMU									
	Very Well		More than Adequately		Adequately		Less Than Adequately		Very Poorly	
	#	%	#	%	#	%	#	%	#	%
Construct a summative project, paper or practiced-based performance that draws on current research, scholarship and/or techniques, and specialized knowledge in the discipline (Applied Learning/ Specialized Knowledge)	156	32.9%	165	34.8%	125	26.4%	24	5.1%	4	0.8%
Analyze data critically, reason logically, and apply quantitative analysis methods correctly to develop appropriate conclusions (Intellectual Skills: Quantitative Fluency)	184	39.0%	155	32.8%	112	23.7%	17	3.6%	4	0.8%
Make and defend assertions about a specialized topic in an extended well-organized document and an oral presentation that is appropriate to the discipline (Intellectual Skills: Communication Fluency)	168	35.8%	173	36.9%	101	21.5%	22	4.7%	5	1.1%
Identify assumptions, evaluate hypotheses or alternative views, articulate implications and formulate conclusions (Intellectual Skills: Critical Thinking)	185	39.2%	160	33.9%	108	22.9%	15	3.2%	4	0.8%

Job and Career Questions

Are you working for pay right now?

	PHYS		CMU	
	#	%	#	%
Yes, full-time	16	84.2%	626	78.6%
Yes, part-time	1	5.3%	87	10.9%
No	2	10.5%	83	10.4%

Only respondents who answered "Yes" they are working for pay right now answered the following questions.

In what type of organization is your principal employment? Mark the one best answer.

	PHYS	CMU
Self-employed in own business or professional non-group practice	2	38
Private for-profit corporation/company/group/group-practice	4	243
Higher education (public or private)	1	50
Elementary or secondary education (public or private)	0	94
International organization in the US	2	16
International organization outside of the US	0	6
US Military	0	7
Federal Government (except military)	3	26
State and local government, institution, or agency (except education)	0	88
Private non-profit organization (except education and international organizations)	1	87
Other	4	41

Which of the following best describes your current position?

	PHYS		CMU	
	#	%	#	%
Entry Level	7	41.2%	255	36.1%
Mid-Level	7	41.2%	339	48.0%
Senior Level	3	17.6%	82	11.6%
Executive Level (except for chief executive)	0	0.0%	12	1.7%
Chief Executive (CEO, COO, CFO, GM or principal in a business of other organization)	0	0.0%	14	2.0%

How many years have you been in your current job type?

	PHYS		CMU	
	#	%	#	%
Less than 3 years	13	76.5%	461	64.8%
3-5 years	4	23.5%	179	25.2%
6-9 years	0	0.0%	41	5.8%
10 or more years	0	0.0%	30	4.2%

Is your current position related to your CMU field(s) of study?

	PHYS		CMU	
	#	%	#	%
Yes, related to major(s)	11	64.7%	531	74.9%
No, not related	6	35.3%	178	25.1%

How well did CMU prepare you for your current career?

	PHYS		CMU	
	#	%	#	%
Very Well	7	41.2%	180	25.5%
More than Adequately	3	17.6%	201	28.5%
Adequately	5	29.4%	247	35.0%
Less Than Adequately	2	11.8%	29	4.1%
Very Poorly	0	0.0%	16	2.3%
NA	0	0.0%	32	4.5%

What is your approximate annual gross income (before taxes)?

	PHYS		CMU	
	#	%	#	%
Under $20,000	0	0.0%	47	7.5%
$20,000 - $29,999	1	5.9%	85	13.6%
$30,000 - $39,999	1	5.9%	144	23.1%
$40,000 - $49,999	1	5.9%	113	18.1%
$50,000 - $59,999	2	11.8%	95	15.2%
$60,000 - $74,999	7	41.2%	67	10.8%
$75,000 - $99,999	3	17.6%	47	7.5%
$100,000 - $149,999	2	11.8%	19	3.0%
$150,000 - $249,999	0	0.0%	3	0.5%
$250,000 - $499,999	0	0.0%	2	0.3%
Over $500,000	0	0.0%	1	0.2%

Only respondents who answered "No" they are not working for pay right now answered the following question:

Why are you not currently working for pay? (Please mark all that apply)

	# of times checked	
	PHYS	**CMU**
I chose not to enter the workforce at this time.	2	9
It has been difficult to find a position in my field.	0	24
It has been difficult to find a position paying an appropriate salary.	0	15
I am raising a family.	0	17
I am currently a student.	0	44
I am doing volunteer work.	0	6
I am retired.	0	4
Other	0	32

Education since College

Have you enrolled in a graduate, professional, or other degree/certificate program since graduating from CMU?

	PHYS		**CMU**	
	#	%	#	%
Yes	10	52.6%	250	31.4%
No	7	36.8%	373	46.9%
No, but I plan to enroll in the next two years.	2	10.5%	173	21.7%

Only respondents who answered "Yes" I have enrolled in another degree/certificate program since graduating from CMU answered the following questions.

Are you enrolled in this program now?

	PHYS		CMU	
	#	%	#	%
Yes, I am a full-time student	3	30.0%	106	42.6%
Yes, I am a part-time student	1	10.0%	32	12.9%
No	6	60.0%	111	44.6%

How long after you graduated from the degree/certificate program this survey pertains to did you start this program?

	PHYS		CMU	
	#	%	#	%
Immediately (following fall or spring)	7	70.0%	114	45.6%
1 Year later	3	30.0%	53	21.2%
2-3 years later	0	0.0%	61	24.4%
4-6 years later	0	0.0%	17	6.8%
NA	0	0.0%	5	2.0%

Altogether, how many years have/did you attend(ed) further schooling? Mark the best answer.

	PHYS		CMU	
	#	%	#	%
None	1	10.0%	15	6.1%
1 - 2 years	6	60.0%	147	59.5%
3 - 4 years	1	10.0%	61	24.7%
5 - 6 years	2	20.0%	16	6.5%
NA	0	0.0%	8	3.2%

How well did CMU prepare you for this educational program?

	PHYS		CMU	
	#	%	#	%
Very Well	3	30.0%	89	35.9%
More than Adequately	5	50.0%	68	27.4%
Adequately	1	10.0%	66	26.6%
Less Than Adequately	1	10.0%	11	4.4%
Very Poorly	0	0.0%	5	2.0%
NA	0	0.0%	9	3.6%

What level of education are/were you pursuing?

	PHYS		CMU	
	#	%	#	%
Certificate	1	10.0%	19	7.7%
Associate	0	0.0%	12	4.9%
Baccalaureate	1	10.0%	25	10.2%
Post-Bacc Certificate	0	0.0%	5	2.0%
Master's	4	40.0%	118	48.0%
J.D.	0	0.0%	27	11.0%
Doctoral	4	40.0%	39	15.9%
Other	0	0.0%	1	0.4%

Did you complete this program?

	PHYS		CMU	
	#	%	#	%
Yes	4	40.0%	85	35.7%
No	2	20.0%	19	8.0%
In the process of finishing	4	40.0%	134	56.3%

Demographic Questions

What is your gender?

	PHYS		CMU	
	#	%	#	%
Male	17	89.5%	313	39.7%
Female	1	5.3%	456	57.9%
Prefer not to respond	1	5.3%	19	2.4%

What is your ethnicity?

	PHYS		CMU	
	#	%	#	%
American Indian or Alaskan Native	0	0.0%	11	1.5%
Asian	0	0.0%	13	1.7%
Black or African American	0	0.0%	6	0.8%
Hispanic of any race	0	0.0%	52	6.9%
Native Hawaiian or Pacific Islander	0	0.0%	4	0.5%
White	14	73.7%	629	83.0%
Two or more races	2	10.5%	31	4.1%

Race and ethnicity unknown	0	0.0%	1	0.1%
Non-Resident Alien (of any race or ethnicity)	0	0.0%	1	0.1%
Prefer not to respond	2	10.5%	4	0.5%
Other	1	5.3%	6	0.8%

What is your current age?

	PHYS		**CMU**	
	#	%	#	%
Under 21	0	0.0%	7	0.9%
21-24	5	26.3%	194	24.5%
25-34	11	57.9%	426	53.9%
35-44	3	15.8%	92	11.6%
45-54	0	0.0%	39	4.9%
55 or older	0	0.0%	18	2.3%
Prefer not to respond	0	0.0%	15	1.9%

Do you live in the state of Colorado?

	PHYS		**CMU**	
	#	%	#	%
Yes	10	52.6%	585	74.0%
No	9	47.4%	206	26.0%

If yes, do you live in Western Colorado?

	PHYS		**CMU**	
	#	%	#	%
Yes	6	60.0%	425	58.1%
No	4	40.0%	307	41.9%

Job and Career Questions (continued)

Comments about your work experience that will improve CMU:

- Take as many STEM courses outside of your major as possible. The more well-rounded you are the better prepared you will be in a professional working environment. Anyone can be an expert in their field, but the ability to have conversations with individuals outside od your discipline is extremely valuable.
- Stay open for in-class education some of us suck at internet learning
- More critical thinking and data analytics
- CMU needs to find a way to connect to the community and local companies to help prepare students who do not desire to pursue higher education immediately after graduation. Finding employment is extremely difficult without internships or real-world experience.
- My undergraduate experience provided a very strong theoretical background that got me hired at my current job.
- Matlab and additional programming are encouraged.

Education since College (continued)

In which field and program are/were you studying and what is the name of the College/University you attend(ed)?

College/University	Field Studying	Level Pursuing
WGU	Computer Science	Baccalaureate
University of Oklahoma	Physics	Doctoral
University of New Mexico	Quantum Computing	Doctoral
University of Colorado at Colorado Springs	Mathematics	Master's
University of Colorado	Aerospace Engineering	Master's
The Pennsylvania State University	Materials Science	Doctoral
Montana State University	Physics	Master's
Fort Hays State University	Computer Science	Certificate
Colorado State	Biomedical Engineering	Master's

General Comments by PHYS Alumni

Other comments about furthering your education:

- I got a Masters at UNM, but decided not to continue on to a PhD. I would not have wasted as much time if I had gotten more research experience earlier in my career. That is mostly UNM’s fault though.

Suggestions for improving the degree/certificate program:

- Please require more computer science courses for the curriculum of Physics majors. A lot of industry jobs require these skills and they would be greatly valued for future employment. Students should be taking courses in Python and Java and it wouldn't hurt to encourage students to minor in C.S to be a more hirable candidate when finished at CMU.
- Make students take two semesters of both quantum and E&M. Encourage students to get research experience either at CMU or through an REU.

- I think that some extra experience in dealing with academic research environments professionally would have been very beneficial.

Additional comments:

- Bring back E&M 2 as a regular course that is taught at CMU (preferably once every 4 semesters) so that those who are considering graduate school have a leg up on other applicants. Many of us who decide to attend graduate school after CMU are required to take the undergrad version of E&M 2 before we can take the graduate level of it. Also, change the text book for Electronics for Scientists!
- After attending a larger research university, I am very aware of the benefits of a smaller program that focuses on the students' education. I hope that Mesa continues to put students first, even as it grows.

Appendix G

David Collins
Department of Physical and Environmental Sciences
Colorado Mesa University
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Email: dacollin@coloradomesa.edu

- **Education**

  - **PhD**, December 1997, University of Texas at Austin.
    Supervisor: Prof. Cecile DeWitt-Morette.
    Specialization: Mathematical Physics, Functional Integration.

  - **BSc (Hons)**, April 1989, Rhodes University, Grahamstown, South Africa.
    Major: Physics Minor: Mathematics. Awarded with distinction.

- **Theses**

  - *Two-state Quantum Systems Interacting with Their Environments: A Functional Integral Approach*, PhD thesis, University of Texas at Austin (1997).
  - *The Use of Groups in Physics with Special Reference to SO(3) and the Euclidean Group*, Honours thesis, Rhodes University (1989).

- **Work Experience**

  - Professor, Physics, Colorado Mesa University (previously Mesa State College), August 2006 – present.
    - Taught various undergraduate physics courses.
    - Supervised undergraduate research and independent study.
    - Conducted and published original research.
    - Performed a wide range of departmental and university service.

  - Visiting Assistant Professor, Physics, Bucknell University, August 2003 -- May 2006.
    - Taught various undergraduate physics courses.
    - Supervised undergraduate research and independent study.

  - Postdoctoral Research Associate, Physics, Carnegie Mellon University, August 2000 -- July 2003.
    - Faculty Supervisor: Prof. R. B. Griffiths.
    - Investigated theoretical quantum computation and quantum information.

  - Postdoctoral Research Associate, Electrical and Computer Engineering, North Carolina State University, January 1998 -- March 2000.
    - Faculty Supervisors: Prof. Ki Wook Kim, Prof. William C. Holton.

        - Investigated theoretical quantum computation and experimental NMR quantum computation.

- Physicist, Optical Engineering Section, Division of Production Technology, CSIR (formerly the Council for Scientific and Industrial Research), Pretoria, South Africa, January 1988 -- March 1988.
    - Devised an algorithm for the computation of the point transfer function of an optical system.

❖ Teaching Experience

- Professor, Physics, Colorado Mesa University/Mesa State College, August 2006 – Present
    - Physics 100: Conceptual physics course.
    - Physics 111: Introductory algebra-based physics course.
    - Physics 111L: Introductory algebra-based physics laboratory.
    - Physics 112: Introductory algebra-based physics course.
    - Physics 112L: Introductory algebra-based physics laboratory.
    - Physics 131: Introductory calculus-based physics course.
    - Physics 131L: Introductory calculus-based physics laboratory.
    - Physics 132: Introductory calculus-based physics course.
    - Physics 132L: Introductory calculus-based physics laboratory.
    - Physics 230: Intermediate thermodynamics, waves and relativity course.
    - Physics 231: Intermediate modern physics course.
    - Physics 252: Intermediate laboratory.
    - Physics 311: Upper division electromagnetism course.
    - Physics 312: Upper division electromagnetism course.
    - Physics 321: Upper division quantum mechanics course.
    - Physics 362: Upper division thermal and statistical physics course.
    - Physics 396: Upper division topics course (quantum optics).
    - Physics 396: Upper division topics course (quantum information).
    - Physics 422: Upper division quantum mechanics course.
    - Physics 473: Upper division optics course.
    - Essl 290: Intermediate level interdisciplinary course (time keeping).

- Visiting Assistant Professor, Physics, Bucknell University, 2003 – 2006
    - Physics 309: Upper division condensed matter physics course.
    - Physics 332: Upper division quantum mechanics course.
    - Physics 222: Sophomore level modern physics course.
    - Physics 141: Introductory level physical science course for non-majors.
    - Physics 329: Upper division physics laboratory.
    - Astronomy 101 Laboratory: Freshman level astronomy laboratory for non-majors.
    - Physics 211/212 Laboratory: Freshman level physics laboratory.
    - Physics 211/212 Problem Session: Discussion sessions for freshman level physics course.

- Independent Study and Undergraduate Research: Supervised undergraduate students in independent study and research in quantum information.

- Co-Instructor, Physics, Carnegie Mellon University, 2001 – 2003
  - Quantum Information and Quantum Computation: Upper division undergraduate/graduate physics elective course.
  - Supervisor: Prof. R. B. Griffiths (course organizer).

- Undergraduate Research Supervision, Physics, Carnegie Mellon University, 2001 – 2002.
  - Supervised undergraduate physics research projects in pulse sequence design for NMR quantum computation.

- Assistant Instructor, Physics, University of Texas, 1993 – 1997
  - Physical Science 303, 304: Introductory level physical science for non-science majors.
  - Supervisor: Prof. Peter R. Antoniewicz.

- Teaching Assistant, Physics, University of Texas, 1991 – 1993
  - Courses: Physics 102M, 102N Laboratories: Freshman level for science (non-physics) majors.
  - Supervisors: Prof. J. David Gavenda (Phy 102M), Prof. Thomas A. Griffy (Phy 102N).

- Tutor, Physics, Rhodes University, 1989 – 1991
  - Physics IP/IL Tutorials: Discussion sessions for freshman level course for science (non-physics) majors.

❖ Research Interests

My primary research area is quantum computation and quantum information. Currently, I investigate methods for estimating parameters that govern quantum processes. I have also investigated implementations of quantum algorithms on ensembles of quantum systems, such as those used in solution state nuclear magnetic resonance (NMR). My work is mostly theoretical, although I have conducted NMR experiments demonstrating quantum information processing. Other research interests include aspects of the foundations of quantum mechanics.

❖ Publications

Undergraduate students are indicated by an asterisk (*).

- *Connecting optical intensities and electric fields using a triple interferometer*, David Collins and Justin Endicott*, Preprint arXiv:2008.12641 (2020).
- *Qubit-channel metrology with very noisy initial states*, David Collins, Phys. Rev. A 99, 012123 (2019).
- *Depolarizing channel parameter estimation using noisy initial states*, David Collins and Jaimie Stephens*, Phys. Rev. A 92, 032324 (2016).

- *Mixed state Pauli channel parameter estimation*, David Collins, Phys. Rev. A 87, 032301 (2013).
- *Probing the qudit depolarizing channel*, Michael Frey, David Collins, and Karl Gerlach, J. Phys. A: Math. Theor. 44, 205306 (2011).
- *Discrimination of unitary transformations in the Deutsch-Jozsa algorithm: Implications for thermal-equilibrium-ensemble implementations*, David Collins, Phys. Rev. A 81, 052323 (2010).
- *Quantum Fisher information and the qudit depolarization channel*, Michael Frey and David Collins, appears in Quantum Information and Computation VII, ed. Eric Donker, et. al., Proceedings of SPIE Volume 7342 (2009).
- *Discrimination of unitary transformations and quantum algorithms*, David Collins, appears in Quantum Communication, Measurement and Computing (QCMC), AIP Conference Proceedings 1110 (2009). Preprint arXiv:0811.1359 (2008).
- *Statistical comparison of ensemble implementations of Grover's search algorithm to classical sequential searches*, Tomasz M. Kott* and David Collins, Phys. Rev. A 77, 052314 (2008).
- *Polarization requirements for ensemble implementations of quantum algorithms with a single bit output*, Brandon M. Anderson* and David Collins, Phys. Rev. A. 72, 042337 (2005).
- *Scaling issues in ensemble implementations of the Deutsch-Jozsa algorithm*, Arvind and David Collins, Phys. Rev. A. 68, 052301 (2003).
- *Shortening Grover's search algorithm for an expectation value quantum computer*, David Collins, Proceedings of the Sixth International Conference on Quantum Communication, Measurement and Computing (QCMC'02), Eds J. H. Shapiro and O. Hirota, (Rinton Press, 2003).
- *Modified Grover's algorithm for an expectation value quantum computer*, David Collins, Phys. Rev. A. 65, 052321 (2002).
- *Orchestrating an NMR quantum computation: the N=3 Deutsch-Jozsa algorithm*, David Collins, K. W. Kim, W. C. Holton, H. Sierzputowska-Gracz, and E. O. Stejskal, Preprint quant-ph/0105045 (2001).
- *NMR quantum computation with indirectly coupled gates*, David Collins, K. W. Kim, W. C. Holton, H. Sierzputowska-Gracz, and E. O. Stejskal, Phys. Rev. A 62 022304 (2000).
- *Deutsch-Jozsa algorithm as a test of quantum computation*, David Collins, K. W. Kim, and W. C. Holton, Phys. Rev. A. 58, 1633 (1998).
- *A Rigorous Mathematical Foundation of Functional Integration*, Cartier, P., Dewitt-Morette, C., Wurm, A. and Collins, D. Contains an appendix on Functional Integration Over Complex Poisson Paths prepared by D. Collins. Functional Integration: Basics and Applications, Eds C. DeWitt-Morette, P. Cartier and A. Folacci, (Plenum Press, New York, 1997).

- **Conference Presentations**

Undergraduate students are indicated by an asterisk (*).

- *Qubit Channel Parameter Estimation with Noisy Initial States*, David Collins, Invited presentation at Advances in Information Geometry Conference, Tokyo, Japan (2020). This conference was canceled as a result of the COVID-19 epidemic.
- *Optimal Estimation of Single Qubit Quantum Evolution Parameters*, David Collins and Michael Frey, APS March Meeting, Portland, Oregon (2010).
- *States Enhanced Estimation of Quantum Evolution Parameters with Entangled*, David Collins and Michael Frey, APS Four Corners Section Meeting, Golden, Colorado (2009).
- *Performance Requirements for Ensemble Implementations of Quantum Algorithms*, David Collins, Brandon Anderson* and Tomasz M. Kott*, APS Four Corners Meeting, Logan, Utah (2006).
- *Polarization Requirements for Ensemble Implementations of Quantum Algorithms with a Single Bit Output*, Brandon Anderson* and David Collins, APS March Meeting, Baltimore, Maryland (2006).
- *Statistical Performance of Ensemble Quantum Computers in Search Algorithms*, David Collins and Tomek Kott*, APS March Meeting, Baltimore, Maryland (2006).
- *Could Quantum Computing Aid Functional Integration?* David Collins, Invited presentation at the MSRI workshop "The Feynman Integral Along with Related Topics and Applications," Berkeley, California (2002).
- *NMR Quantum Computation with Indirectly Coupled Gates*, David Collins, W. C. Holton, K.W. Kim, H. Sierzputowska-Gracz, and E. O. Stejskal, APS March Meeting, Minneapolis, Minnesota (1999).
- *Deutsch-Jozsa Algorithm on a NMR Quantum Computer: Issues and Progress*, David Collins, W. C. Holton, K. W. Kim, H. Sierzputowska-Gracz, and E. O. Stejskal, APS Centennial Meeting, Atlanta, Georgia (1999).
- *Using NMR to Implement a Quantum Computer*, David Collins, H. Sierzputowska-Gracz, W. C. Holton, K.W. Kim and E. O. Stejskal, Triangle Magnetic Resonance Group meeting, Chapel Hill, North Carolina (1998).
- *A Refinement of the Deutsch-Jozsa Algorithm*, David Collins, K.W. Kim and W. C. Holton, DARPA Ultrascale Computing principle investigators' meeting, Tucson, Arizona (1998).
- *Spinor Structures: A New Approach*, David Collins, F. A. M. Frescura, and G. Lubczonok, 26th Annual Seminar on Theoretical Physics, Bloemfontein, South Africa. Published in the conference proceedings (1991).
- *Moving Frames and Accelerated Observers in Special Relativity*, David Collins and F. A.M. Frescura, 25th Annual Seminar on Theoretical Physics, Port Elizabeth, South Africa. Published in the conference proceedings (1990).

Conference Posters

Undergraduate students are indicated by an asterisk (*).

- *Qubit Channel Parameter Estimation with Very Noisy Initial States,* David Collins, 22nd Annual Conference on Quantum Information Processing (QIP), Boulder, CO (2019). Similar poster of earlier work presented at 20th Annual SQuInT Workshop, Santa Fe, NM (2018).

- *Quantum Channel Parameter Estimation with Noisy Initial States,* David Collins and Jaimie Stephens*, 18th Annual SQuInT Workshop, Albuquerque, NM (2016).
- *Enhanced Noisy Depolarizing Channel Parameter Estimation*, David Collins and Jaimie Stephens*, 9th Conference on the Theory of Quantum Computation, Communication and Cryptography (TQC 2014), Singapore (2014).
- *Correlated Quantum States and Enhanced Mixed State Pauli Channel Parameter Estimation,* David Collins, International Conference on Quantum Information and Quantum Computing, Bangalore, India (2013).
- *No Advantage to Entanglement in Bit-Flip Parameter Estimation*, David Collins and Michael Frey, International Conference on Quantum Information, Ottawa, Canada (2011).
- *Discrimination of Unitary Transformations and Quantum Algorithms,* David Collins, 9th International Conference on Quantum Communication, Measurement and Computing, Calgary, Canada (2008).
- *Scaling Issues in Ensemble Quantum Algorithms,* David Collins and Arvind, Quantum Information and Quantum Control Conference, Toronto, Canada (2004).
- *Shortening Grover's Search Algorithm for an Expectation Value Quantum Computer,* David Collins, 6th International Conference on Quantum Communication, Measurement and Computing, Cambridge, Massachusetts (2002).
- *NMR Quantum Computation with Indirectly Coupled Gates,* David Collins, W. C. Holton, K. W. Kim, H. Sierzputowska-Gracz, and E. O. Stejskal, 41st Experimental Nuclear Magnetic Conference, Pacific Grove, California (2000).
- *Deutsch-Jozsa Algorithm on an NMR Quantum Computer,* David Collins, W. C. Holton, K. W. Kim, H. Sierzputowska-Gracz, and E. O. Stejskal, Triangle Magnetic Resonance Group meeting, Research Triangle Park, North Carolina (1999).
- *Deutsch-Jozsa Algorithm on an NMR Quantum Computer: Issues and Progress,* David Collins, W. C. Holton, K. W. Kim, H. Sierzputowska-Gracz, and E. O. Stejskal, Conference on Quantum Information Processing and NMR, Cambridge. Massachusetts (1999).

Workshops Attended

- Quantum Undergraduate Education and Scientific Training, Virtual Workshop, June 2021.
- AAPT Workshop for New Physics and Astronomy Faculty, Greenbelt, Maryland, June 2008.
- 15th Waterloo NMR Summer School, University of Waterloo, Waterloo, Ontario, Canada, June 1999.
- Quantum Computations Tutorial, APS March Meeting, Los Angeles, California, March 1998.
- NATO ASI Functional Integration: Basics and Applications, Cargese, Corsica, France, September 1996. Funding provided by Collectivite Territorial de Corse.

University and Departmental Service

Major university and departmental service includes:

- CMU Faculty Senate President, 2020-2021.
- CMU Physics program coordinator, 2013 – present.
- Chair of three physics search committees 2018-2020.

- **Professional Organizations**

  - Member: American Physical Society

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email: chmiddle@coloradomesa.edu
www.coloradomesa.edu/_chmiddle

Education
Ph.D., Physics, UT, Knoxville, December 2005, Advisor: Dr. George Siopsis
B.S., Physics; Minor, Mathematics (cum laude), Eastern Illinois University, May 1998

Scholarships and Awards
- CMU Associated Student Government (ASG) *Faculty Member of the Year*, 2017-18
- CMU Exemplary Faculty Award, 2006-07, 2014-15, 2016-17
- Faculty Professional Development Grant, 2007-08, 2009-10, 2011-12, 2016-17, 2018-19
- Faculty Professional Travel Grant, 2005-06
- SPS Outstanding Chapter Award, 06-07, 07-08, 08-09, 10-11, 11-12, 12-13, 13-14, 14-15
- APS Topical Group in Gravitation *Best Student Presentation*, 8th ECGM, SP 05
- 2002 University of Tennessee *Outstanding Graduate Teaching Assistant*
- SARIF Graduate Research Assistant Research Grant, SU 03, SU 05
- DPF Travel Award Recipient, APS April 2004 Meeting, SP 04, SP 05
- Science Alliance Fellowship, FA 99-SP 01
- Glenn Lefler Physics Scholarship, FA 96
- College of Sciences Undergraduate Investigator Award, SP 97
- Certificate of Achievement for Contributions to Undergraduate Research, SP 97
- College of Sciences Dean's List: FA 95, SP 96, SP 97, FA 97, SP 98

Academic Experience

Professor of Physics, Colorado Mesa University
Department of Physical and Environmental Sciences, 08/15-present

Associate Professor of Physics, Colorado Mesa University
Department of Physical and Environmental Sciences, 08/10-08/15

Assistant Professor of Physics, Colorado Mesa University
Department of Physical and Environmental Sciences, 08/06-08/10
- Granted tenure, FA12
- Faculty Trustee, FA17-SP19
- Faculty Senate, FA13-present; President-elect FA14-SP15; President FA15-SP16
- Handbook Revision Committee, SP20-present
- Academic Policies Committee, FA19-present
- Strategic Planning Committee, FA15-SP16
- Working Group to Improve Student Academic Success (WIGISAS 4.0), FA16-SP17
- Tenure and Promotion Committee, FA13, FA20

- Faculty Advisor for the Society of Physics Students, FA06-SP15
- Chapter Advisor for Sigma Pi Sigma, SP08-SP13, SP20-present
- Graduate Curriculum Committee, SP07-FA12
- Tutorial Services Advisory Committee, SP08-FA13
- Distinguished Faculty Award Committee, SP08, SP16
- VPAA Search Committee, FA14-SP15, FA15-SP16
- Physics Faculty Search Committee, chair, SP17
- Physics Faculty Search Committee, FA18-SP19
- Chemistry Faculty Search Committee, FA08-SP09
- Mechanical Engineering Faculty Search Committee, SP10
- Library Director Search Committee, SP11-SU11
- Lecturer of Physics Search Committee, SP10-SU10
- Degree Distinction/ General Education Committee, FA08-SP09
- Higher Learning Commission Criterion 4 Subcommittee, FA11-FA13
- Little Mavericks Learning Center, Board of Trustees, FA09-SU15

Assistant Professor of Physics, Rhodes College Dept of Physics, 08/05-08/06
- Codesigned four-part lecture series entitled "An Introduction to General Relativity and Differential Geometry" with math department colleague
- Presented one of five mini-lectures collectively entitled "From Atoms to Space-time: The Einsteinian Revolution", The Paul Barret Jr. Library Dedication Ceremony

Research Assistant, University of Tennessee Dept of Physics and Astronomy, 08/01-08/05
- Theoretical research focusing primarily on general relativistic calculations of a 3-brane embedded in a at *D*-dimensional, infinite-volume bulk (DGP Model)
- Collaborative research work involving REU student, SU 2004

Teaching Assistant, University of Tennessee Dept of Physics and Astronomy, 08/99-08/05
- Instructed freshman honors lab/recitation and introductory physics/astronomy labs and recitations
- Guest lectured for Elements of Physics, Honors Fundamentals of Physics and undergraduate and graduate-level Classical Mechanics

Science Alliance Internship, Theoretical Nuclear Physics Group, ORNL, SU 00
- Computational work examining nuclear structure through Mean-Field Theory interactions

Research Experience for Undergraduates, University of Notre Dame, SU 97
- Experimental work examining the ^{8}B solar neutrino spectrum and the alpha decay of ^{8}Be

Courses Taught
- Topics: General Relativity - SP07, SP11, SP17, SP19
- Topics: Middle School Physics - SU08
- Senior Research - FA17, SP18, FA18, SP19
- Physics Seminar - FA08, FA09, FA10, FA11, FA12, FA13, FA14, FA15, FA16, SP20, FA20, FA21

- Electromagnetic Theory I - FA12, FA13, FA18, FA21
- Advanced Dynamics - SP08, SP09, SP10, SP11, SP12, SP13, SP15, SP20
- Quantum Theory I - FA05, FA09, FA11, SP18, SP20, SP21
- Quantum Theory II - SP10, SP12, SP14, SP16
- Modern Optics - FA06, FA07, FA08, FA09, FA10
- Modern Physics I - FA06, FA07, FA08
- Modern Physics II - SP06, SP07, SP08, SP09
- Intermediate Dynamics - FA14, FA15, FA16, FA17
- Fundamental Mechanics - FA08, FA09, FA10, FA11, FA17, FA18, FA20
- Fundamental Mechanics Lab - FA08, FA10, FA11, FA12, FA13, FA14, FA16
- Electromagnetism & Optics - SP13, SP14, SP15, SP16, SP17
- Electromagnetism & Optics Lab - SP13, SP15, SP16, SP17
- General Physics I & II - FA05, SP06, FA06, SP07, FA07, SP08, SP09, SP10, SP11, SP18, SP19, SP20, SP21
- General Physics I & II Lab - FA99 - FA05, SP07, FA07, SP08, SP09, SP11, SP21, FA21
- Concepts of Physics - SP12, FA12, FA13, FA14, FA15, FA16
- Astronomy Lab - FA99, SP06

Other Experience

Undergraduate Research

- Theoretical cosmological research of the superstring corrected Einstein field equations of an adiabatically expanding Robertson-Walker universe extended to 10D
- Theoretical plasma research of a uniformly magnetized, homogeneous plasma with species described by drifting bi-Maxwellian distribution functions

Member of Society of Physics Students, Eastern Illinois University, FA95 - SP98, Elected vice-president, SP98

Professional Affiliations

- Member, Sigma Pi Sigma
- Member, American Physical Society
- Member, APS Topical Group in Gravitation
- Member, American Association of Physics Teachers
- Elected associate member of Sigma Xi, Scientific Research Society, 1998

Peer-Reviewed Publications

- "Anisotropic evolution of D-dimensional FRW spacetime", C. Middleton, **B.A. Brouse**[1], **S.D. Jackson**[1], *Eur. Phys. J. C* (2019) 79: 982, arXiv:1902.00130
- "Elliptical-like orbits on a warped spandex fabric: A theoretical/experimental undergraduate research project", C. Middleton and **D. Weller**[1], *Am. J. Phys*. **84** (4), April 2016, gr-qc/1601.03996
- "The 2D surfaces that generate Newtonian and general relativistic orbits with small eccentricities", C. Middleton, *Am. J. Phys.* **83** (7), July 2015, gr-qc/1506.03342
- "Circular orbits on a warped spandex fabric", C. Middleton and **M. Langston**[1], *Am. J. Phys.* **82** (4), April 2014, physics.class-ph/1312.3893

- “Anisotropic evolution of 5D Friedmann-Robertson-Walker spacetime", C. Middleton and **E. Stanley**[1], *Phys. Rev. D* **84**, 085013 (2011), gr-qc/1107.1828
- “The High Road/Low Road Demonstration or Birds on a Wire", **Jacob Cady**[1] and Chad A. Middleton, *J. of Undergraduate Research in Physics*, 22, (Dec. 2009)
- “Kayaking Physics: The Tipping Angle", **Daniel R. Rottinghaus**[1] and Chad A. Middleton, *J. of Undergraduate Research in Physics*, 22, (Aug. 2009)
- “Solutions of Higher Dimensional Gauss-Bonnet FRW Cosmology", K. Andrew, B. Bolen, and C. Middleton, *Gen. Rel. and Grav.,* Vol. 39, Num. 12 (2007) pps. 2061-2071;
- gr-qc/0708.0373
- “AdS/CFT Correspondence with Heat Conduction", J. Alsup, C. Middleton, and G. Siopsis, *Phys. Lett. B*, Vol. 654 (2007) pps. 35-40; hep-th/0607139
- “Using a Brane to Probe the Bulk", Chad A. Middleton, *Mercury*, Journal of the Astronomical Society of the Pacific, Vol. 35 (2006) No. 2
- “Constrained Perturbative Expansion of the DGP Model", C. Middleton and G. Siopsis, *Phys. Lett. B*, Vol. 613 (2005) pps. 189-196; hep-th/0502020
- “The Schwarzschild Solution in the DGP Model", C. Middleton and G. Siopsis, *Mod. Phys. Lett. A*, Vol. 19 (2004) pps. 2259-2266; hep-th/0311070

[1]Author names listed in bold indicate CMU undergraduate students

Conference Presentations

- C. Middleton, “A possible higher-dimensional alternative to scalar-field inflationary theory", 22nd International Conference on General Relativity and Gravitation, July 7-12, 2019, Valencia, Spain
- C. Middleton, “A possible higher-dimensional alternative to scalar-field inflationary theory", 35th Jim Isenberg Pacific Coast Gravity Meeting, March 29-30, 2019, Utah State University
- C. Middleton, “Elliptical-like orbits on a warped spandex fabric: A theoretical/ experimental undergraduate research project", Joint Meeting of the Four Corners and Texas Sections of the APS, October 21-22, 2016, New Mexico State University
- C. Middleton, “Newtonian and general relativistic orbits with small eccentricities on 2D surfaces", APS Four Corners Section Meeting, October 17-18, 2014, Utah Valley University
- C. Middleton, “Circular orbits on a warped spandex fabric", APS Four Corners Section Meeting, October 18-19, 2013, University of Denver, CO
- C. Middleton, “Anisotropic evolution of 5D Friedmann-Robertson-Walker spacetime", 21st Midwest Relativity Meeting, November 4-5, 2011, UIUC
- C. Middleton, “Anisotropic Evolution of *D*-Dimensional Spacetime", APS Four Corners Section Meeting, October 23-24, 2009, Golden, CO
- C. Middleton, “Anisotropic Evolution of *D*-Dimensional Spacetime", APS April 2009 Meeting, May 2-5, 2009, Denver, CO
- C. Middleton, “Higher Dimensional Gauss-Bonnet FRW Cosmology", SPS Zone 14 Regional Meeting, November 10, 2007, Mesa State College
- K. Andrew, B. Bolen, and C. Middleton, “Dynamical Compactification of *D*-Dimensional Gauss-Bonnet FRW Cosmology", 16th Midwest Relativity Meeting, November 17-18, 2006, Washington University

- K. Andrew, B. Bolen, and C. Middleton, “Effects of Dynamical Compactification of *D*-Dimensional Gauss-Bonnet FRW Cosmology", APS Four Corners Section 2006 Fall Meeting, October 6-7, 2006, Utah State University
- C. Middleton and G. Siopsis, “Constrained Perturbative Expansion in the DGP Model", APS April 2005 Meeting, April 16-19, 2005, Tampa, FL
- C. Middleton and G. Siopsis, “Constrained Perturbative Expansion in the DGP Model", 8th East Coast Gravity Meeting, March 19, 2005, Wake Forest University
- C. Middleton and G. Siopsis, “The Schwarzschild Solution in the DGP Model", APS April 2004 Meeting, May 1-4, 2004, Denver, CO
- C. Middleton and G. Siopsis, “Fat Branes in Infinite-Volume Extra Space", 19th Pacific Coast Gravity Meeting, March 1, 2003, University of Utah
- C. Middleton, S. Ness, K. McGlynn, D. Pakey, J. Conwell, K. Andrew, “A Cosmological Polytropic Equation of State Applied to the First Order Classical Superstring Corrections to the Einstein Field Equations", Joint Meeting of The Illinois Section of AAPT and The Society of Physics Students, April 11, 1997, Illinois State University

Other Presentations

- C. Middleton, “Scientific Cosmology: A Quest to Comprehend the Universe", Telluride Council for the Arts, June 25, 2009, Telluride, CO
- C. Middleton, “Gravity, Blackholes, and Cosmology", Astronomy Camp, June 22, 2009, Western Colorado Math and Science Center
- C. Middleton, “Using a Brane to Probe the Bulk", APS World Year of Physics
- Speakers Bureau Invited Speaker, Sigma Pi Sigma Induction Ceremony, April 22, 2006, Austin Peay State University
- C. Middleton, “Gravity in Extra Dimensions of Infinite Volume", August 1, 2005, Ph.D. Dissertation Defense, University of Tennessee Dept of Physics
- C. Middleton, “Gravity, D-branes, String Theory, and Large Extra Dimensions", Tennessee Governor's School for the Sciences, Summer 2005, University of Tennessee
- C. Middleton, “Gravity, D-branes, and Large Extra Dimensions", Department of Energy Grant Review, January 25, 2005, University of Tennessee
- C. Middleton, “Why Branes?", Physics Department Colloquium Series, March 24, 2003, Eastern Illinois University

Workshop Attendance

“13th Workshop for New Physics and Astronomy Faculty", American Center for Physics, College Park, MD, June 25-29, 2008

Brian D. Hosterman, Ph.D.
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Education

Ph.D., Physics, University of Nevada, Las Vegas, NV, August 2011.
Dissertation: *Raman spectroscopic study of solid solution spinel oxides*.

M.S., Physics, University of Nevada, Las Vegas, NV, December 2006.
Thesis: *Micro-Raman spectroscopic study of the corrosion of stainless steel by lead-bismuth eutectic*.

B.S., Physics, Cum Laude with Honors, Denison University, Granville, OH, May 2001.
Honors project: *Ni II and Co I branching fractions in the UV*.

Work Experience

Associate Professor of Physics, Department of Physical and Environment Sciences, Colorado Mesa University, Grand Junction, 2020 – present.

Assistant Professor of Physics, Department of Physical and Environment Sciences, Colorado Mesa University, Grand Junction, 2014 – 2020.

Postdoctoral Research Associate, Division of Natural Sciences, New College of Florida, Sarasota, FL, 2011 – 2014.

Teaching Assistant, various calculus and non-calculus based introductory laboratory classes, Department of Physics and Astronomy, University of Nevada, Las Vegas, NV, 2001 – 2011.

Teaching Assistant, introductory calculus-based physics laboratory, Department of Physics and Astronomy, Denison University, OH, 1999 – 2001.

Teaching Experience

Associate/Assistant Professor, Colorado Mesa University.

PHYS 111 – Introductory algebra-based physics course.
PHYS 111L – Introductory algebra-based physics laboratory.
PHYS 112 – Introductory algebra-based physics course.
PHYS 112L – Introductory algebra-based physics laboratory.

PHYS 131 – Introductory calculus-based physics course.
PHYS 131L – Introductory calculus-based physics laboratory.
PHYS 132 – Introductory calculus-based physics course.
PHYS 132L – Introductory calculus-based physics course.
PHYS 230 – Intermediate thermodynamics, relativity, and waves course.
PHYS 251 – Electronics course and laboratory.
PHYS 252 – Intermediate physics laboratory.
PHYS 331 – Upper level physics laboratory.
PHYS 342 – Upper level classical mechanics course.
PHYS 362 – Upper level thermal and statistical physics course.
PHYS 441 – Upper level solid state physics course.
PHYS 494 – Upper level physics seminar.

Teaching assistant, University of Nevada, Las Vegas.

PHYS 151L – Introductory algebra-based physics laboratory.
PHYS 152L – Introductory algebra-based physics laboratory.
PHYS 180L – Introductory calculus-based physics laboratory.
PHYS 181L – Introductory calculus-based physics laboratory.
PHYS 182L – Introductory calculus-based physics laboratory.

Teaching assistant, Denison University.

PHYS 121L – Introductory calculus-based physics laboratory.

Publications

M. Sendova, B. Hosterman, A. Grebe, *In-situ isothermal micro-Raman spectroscopy reveals the activation energy of dehydration in alpha-FeOOH*, J. Raman Spectrosc., 48, 618-622, 2017.

R. Raud, B. Hosterman, A. Diana, T. Steinberg, G. Will, *Experimental study of the interac tivity, specific heat, and latent heat of fusion of water based nanofluids*, Appl. Therm. Eng., 117, 164-168, 2017.

V. Khranovskyy, M. Sendova, B. Hosterman, N. McGinnis, I. Shtepliuk, R. Yakimova, *Temperature dependent study of basal plane stacking faults in Ag:ZnO nanorods by Raman and photoluminescence spectroscopy*, Mater. Sci. Semicond. Process., 69, 62-67, 2016.

M. Sendova, B. Hosterman, R. Raud, T. Hartmann, D. Koury, *Temperature-dependent, micro-Raman spectroscopic study of $BaTiO_3$ nanoparticles*, J. Raman Spectrosc., 46, 25-31, 2015.

C. Gross, M. Peprah, B. Hosterman, T. Brinzari, P. Quintero, M. Sendova, M. Meisel, D. Talham, *Light-induced magnetization changes in a coordination polymer heterostructure of prussian blue analogue and a hofmann-like Fe(II) spin crossover compound*, J. Am. Chem. Soc., 136, 9846-9849, 2014.

J. Jimenez, M. Sendova, B. Hosterman, L. Haney, *Sn centers-mediated enhancement of 1.53 µm emission of Er^{3+} ions in phosphate glass*, Mater. Lett., 131, 344-346, 2014.

M. Sendova, B. Hosterman, *Raman spectroscopic study of the size-dependent order parameter of barium-titanate*, J. Appl. Phys., 115, 214104, 2014.

B. Hosterman, J. Farley, A. Johnson, *Spectroscopic study of the vibrational modes of mag nesium nickel chromite, $Mg_xNi_{1-x}Cr_2O_4$*, J. Phys. Chem. Solids, 74, 985-990, 2013.

A. Johnson, D. Koury, J. Welch, T. Ho, S. Sidle, C. Harland, B. Hosterman, U. Yuomas, L. Ma, J. Farley, *Spectroscopic and microscopic investigation of the corrosion of D-9 stainless steel by lead-bismuth eutectuc (LBE) at elevated temperatures: Initiation of thick oxide for mation*, J. Nucl. Mater., 376, 265-268, 2008.

A. Johnson, E. Loewen, T. Ho, D. Koury, B. Hosterman, J. Welch, J. Farley, *Spectroscopic and microscopic study of the corrosion of iron-silicon steel by lead-bismuth eutectic (LBE) at elevated temperatures*, J. Nucl. Mater., 350, 221-231, 2006.

A. Johnson, D. Parsons, J. Manzerova, D. Perry, D. Koury, B. Hosterman, J. Farley, *Specotrscopic and microscopic investigation of the corrosion of 316/316L stainless steel by lead-bismuth eutectic (LBE) at elevated temperatures: importance of surface preparation*, J. Nucl. Mater., 328, 88-94, 2004.

Conference Presentations

Lead-bismuth eutectic – chemistry and corrosion – imaging and Raman studies, A. Johnson, B. Hosterman, J. Farley, shared oral presentation at combined workshop: 2nd Annual U. S. Department of Energy Nuclear Energy Programs Materials Science and Engineering Materials Cross-cut Workshop and 5th Annual Asia-Pacific Nuclear Energy Forum on Materials for Nuclear Applications, Berkeley, CA, June 23, 2011.

Laser micro-Raman study of corrosion in materials for nuclear applications, B. Hosterman, J. Farley, A. Johnson, American Nuclear Society Winter Meeting, Las Vegas, NV, November 10, 2010.

Liquid metal coolants (LBE) for fast-flux nuclear applications: corrosion of steel, J. Farley, D. Koury, B. Hosterman, T. Ho, L. Wilson, M. Vasquez, American Nuclear Society Winter Meeting, Reno, NV, November 11, 2008.

Corrosion of steel by lead-bismuth eutectic, J. Farley, A. Johnson, B. Hosterman, T. Ho, D. Koury, U. Younas, American Nuclear Society Student Conference, Madison, WI, April 2, 2004.

Ni II and Co I branching fractions in the UV, B. Hosterman, N. Gibson, poster presentation at American Physical Society Ohio section fall meeting, Toledo, OH, October 14, 2000.

Grants Awarded

Developing and Implementing Open Education Resources (OER) Materials for GT-Pathways Introductory Physics Courses (PHYS 111, 112, 131, 132) at Colorado Mesa University, Y. Kim (PI), B. Hosterman (Co-PI), C. Whiting (Co-PI), $9,600, Colorado Department of Higher Education, 2021.

Workshops Attended

Workshop for New Physics and Astronomy Faculty, American Association of Physics Teachers, College Park, MD, June 22–25, 2015.

Building a Thriving Undergraduate Physics Program, American Association of Physics Teachers, Seattle, WA, February 5–8, 2015.

Youngmin Martin Kim
Assistant Professor of Physics
Physical and Environmental Sciences
Email: ykim@coloradomesa.edu

Assistant Professor of Physics, Colorado Mesa University, CO USA (2019 – Present)

EDUCATION

Ph.D. in Physics, University of Paderborn, Germany (2010 – 2013)
M.S. in Physics, University of Paderborn, Germany (2008 – 2010) – Ph.D. integrated program
B.S. in Physics and in Mathematics, Pacific Union College, CA (2003-2007)

TEACHING APPOINTMENTS

2019-2021, **Colorado Mesa University,** CO USA

- PHYS 111, 111L: General Physics & Laboratory
- PHYS 131, 131L: Fundamental Mechanics & Laboratory
- PHYS 230: Intermediate Dynamics
- PHYS 252: Intermediate Laboratory
- PHYS 395: Independent Research
- PHYS 396: Light Science and Application (Modern Optics)

2010-2013**, University of Paderborn**, Germany
Teaching and Research Assistant in Department of Physics,

RESEARCH APPOINTMENTS

2017 - 2019, **University of Maryland,** MD USA
Postdoctoral Researcher *in Physics*,
In collaboration with Prof. Christopher Monroe's group
Field of expertise: Non-local quantum interaction of Trapped-ion qubits in Photonic circuits

2016, **University of Paderborn,** Germany
Transregio Fellow,
Field of expertise: InGaN/GaN semiconductor quantum emitters in pyramidal structures

2013 – 2016, **Korean Advanced Institute for Science and Technology (KAIST),** South Korea
Postdoctoral Researcher *in Physics and in Material Sciences*,
Field of expertise: Quantum photonics by controlling quantum dot and surface plasmon, Field-free switching of magnetization through spin-orbit torques

2012, **Stanford University**, CA USA

Student Research Fellow at Prof. Yoshihisa Yamamoto's group
Field of expertise: *Optical control of single electron spin as qubits in solid-state*

PUBLICATIONS (*Equal contribution)

Jong-Hoi Cho*, Youngmin M. Kim*, Seung-Hyuk Lim, Hwan-Seop Yeo, Sejeong Kim, Su-Hyun Gong, and Yong-Hoon Cho, "*Strongly coherent single photon emission from site-controlled InGaN quantum dots embedded in GaN nano-pyramids*", ***ACS Photonics*** ***(Impact Factor: 6.880)***, 2018, *5* (2), pp 439–444 *equally contributed (1st)

Young-Wan Oh, Seung-heon Chris Baek, Y. M. Kim, Hae Yeon Lee, Kyeong-Dong Lee, Chang-Geun Yang, Eun-Sang Park, Ki-Seung Lee, Kyong-Whan Kim, Gyungchoon Go, Jong-Ryul Jeong, Byong-Chul Min, Hyun-Woo Lee, Kyung-Jin Lee & Byong-Guk Park, *"Field-free switching of perpendicular magnetization through spin-orbit torque in antiferromagnet/ferromagnet/oxide structures",* **Nature Nanotechnology** ***(Impact Factor: 38.986)*** 11, 878–884 (2016)

Kyeong-Dong Lee, Young Min Kim, Hyon-Seok Song, Chun-Yeol You, Jung-Il Hong and Byong-Guk Park. *"Speed and stability of magnetic chiral motion in a chain of asymmetric thin nanodots"*, **Applied Physics Express**, Vol. 8, Nr. 10 (2015)

Y. M. Kim, D. Sleiter, K. Sanaka, D. Reuter, K. Lischka, Y. Yamamoto, A. Pawlis, *"Optically controlled initialization and read-out of an electron spin bound to a fluorine donor in ZnSe"*, ***Current Applied Physics***, Vol. 14, 9 (2014)

D. Sleiter, K. Sanaka, Y. M. Kim, K. Lischka, A. Pawlis, and Y. Yamamoto, *"Optical Pumping of a Single Electron Spin Bound to a Fluorine Donor in a ZnSe Nanostructure"* ***Nano Letters*** ***(Impact Factor: 12.080)****,* 2013, 13 (1), pp 116–120

Y.M. Kim, D. Sleiter, K. Sanaka, Y. Yamamoto, J. Meijer, K. Lischka, and A. Pawlis, *"Optical properties of fluorine implanted ZnMgSe/ZnSe quantum-well nanostructures"*, ***Proc. SPIE*** 8272, 827213 (2012)

Y.M. Kim, D. Sleiter, K. Sanaka, Y. Yamamoto, J. Meijer, K. Lischka, and A. Pawlis, *"Semiconductor qubits based on fluorine implanted ZnMgSe/ZnSe quantum-well nanostructures"*, ***Physics Review B*** 85, 085302 (2012)

Total Citations (*since 2016)*: 360

GRANT & FELLOWSHIP
2021, **CDHE-OER Grant recipient as PI**: Colorado Department of Higher Education
2019, **NSF-CASIS**: *Individual and Collective Behavior of Active Colloids in Microgravity,* as Co-PI
2016, **Transregio Fellowship recipient** from Germany
2015, **NRF**, Natural Science BA20409
Title: Research on quantum photonics by controlling semiconductor quantum dot and surface plasmon
Amount and duration: ca. $6,500,000 for 3 years

2013, **NRF-DFG** Collaborative Research programme
Title: Electrical control of Fluorine Donor Bound Electrons in ZnMgSe/ZnSe QWs nanostructures
Amount and duration: ca. $170,000 for 2 years
Brain Korea 21 (BK 21) Fellowship recipient for outstanding young postdoctoral researcher

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INVITED TALKS AND CONFERENCE PRESENTATIONS

2019-2021, **Seminar Talk**, Colorado Mesa University, CO USA
2018**, Invited Talk,** KASE Conference on Science, Technology, and Entrepreneurship, NY USA
Poster, KASE Conference on Science, Technology, and Entrepreneurship, NY USA
Poster, NSF ACQUIRE Review meeting, D.C. USA
Poster, Defense Advanced Research Projects Agency (DARPA), VA USA
Poster, Quantum Information Science and Atomic and Molecular Physics Program Reviews, Air Force Office of Scientific Research, VA USA
Poster, CLEO Conference, CA USA
2016**, Invited Talk,** University of Paderborn, Germany
Invited Talk, Juelich Forschungszentrum, Germany
Invited Talk, Pohang University of Science and Technology (POSTECH), South Korea
Oral presentation, 18th International Symposium on Physics of Semiconductors, South Korea,
2015**, Invited Talk,** Korea Advanced Institute for Science and Technology (KAIST)
Invited Talk, Korean Optical Society Annual Conference, South Korea
2014**, Invited Talk**, Pohang University of Science and Technology (POSTECH), South Korea
Invited Talk, Korea Research Institute of Standards and Science (KRISS), South Korea
Oral presentation, Korean-German-French Workshops on Nanophotonics, South Korea

2013**, Invited Talk,** Pohang University of Science and Technology (POSTECH), South Korea
Invited Talk, Korea Advanced Institute for Science and Technology (KAIST), South Korea
Oral presentation, Korean Physical Society Annual Conference, South Korea
2012**, Oral presentation,** SPIE Photonics West Conference, CA USA,

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SERVICES

2021-Present, **Membership Director**, Association of Korean Physicists in America (AKPA)

2020-Present, **Council Member**, Colorado Department of Higher Education (CDHE-OER)
Scholarship Chair, Korean American Scholarship Foundation (MSRC)

LANGUAGES

English (fluent), Korean (native), German (advanced)

Catherine Ann Whiting
Assistant Professor
Department of Physical and Environmental Sciences, Physics Program
Colorado Mesa University
Grand Junction, CO 81501
cwhiting@coloradomesa.edu

Education

- Ph.D., Physics, University of Iowa, August 2008-2015
- **M.S. in Astronomy, August 2008- May 2010, University of Iowa, Iowa City, IA**
- B.S. in Physics, Astronomy, and Mathematics (with High Distinction), August 2004- May 2008, University of Iowa, Iowa City, IA

Employment

- Assistant Professor, Colorado Mesa University, Grand Junction, CO, 2020-
- Visiting Assistant Professor, Bates College, Lewiston, ME, 2018-2020
- Postdoctoral Fellow, National Institute for Theoretical Physics, School of Physics, University of the Witwatersrand, Johannesburg, South Africa, 2015-2018
- Sessional Lecturer, School of Physics, University of the Witwatersrand, Johannesburg, South Africa, 2017
- Graduate Teaching Assistant, Department of Physics and Astronomy, University of Iowa, Iowa City, IA, 2009-2015
- Lecturer, Grinnell College, Grinnell, IA, 2014
- Graduate Research Assistant, Department of Physics and Astronomy, University of Iowa, Iowa City, IA, 2008-2009
- Undergraduate Research Assistant, Department of Physics and Astronomy, University of Iowa, Iowa City, IA, 2005-2008,
- REU Intern, Institute for Astronomy, University of Hawaii, Honolulu, HI, 2007
- REU Intern, National Radio Astronomy Observatory, Array Operations Center, Socorro, NM, 2006
- Peer Tutor, University of Iowa TRiO Student Support Services, undergraduate physics and astronomy courses, 2008-2013

Teaching

Colorado Mesa University, Assistant Professor

- PHYS 471: Computational Physics (Fall 2021), sophomore-senior level
- PHYS 494: Physics Seminar (Fall 2021, Spring 2021), senior physics majors
- PHYS 111: General Physics (Fall 2021, Spring 2021, Fall 2020), introductory level, algebra based
- PHYS 101: Elementary Astronomy (Fall 2021, Spring 2021, Fall 2020), introductory level

Bates College, Visiting Assistant Professor

- PHYS 108: Introduction to Modern Physics (Winter 2020), introductory level

- PHYS 211: Newtonian Mechanics (Fall 2019), sophomore level, physics and engineering majors
- PHYS 107: Classical Physics (Fall 2019, Fall 2018), introductory level, covering mechanics and E&M, calculus based
- PHYS 107L: Classical Physics Lab (Fall 2019), introductory level, covering mechanics and E&M, calculus based
- ATPH 336: General Relativity (Winter 2019), new course, sophomore-senior level
- PHYS 108L: Modern Physics Lab (Winter 2019), introductory level

University of the Witwatersrand, Sessional Lecturer

- PHYS4021A: Introduction to General Relativity, Undergraduate Honours Level, cotaught with Dr. Nilanjan Sircar

University of Iowa, Graduate TA

- PHYS:1702: Physics II Lab (Spring 2015, Spring 2014), freshman level, physics majors
- PHYS:1612: Introductory Physics I TILE Discussion (Spring 2015), introductory level
- PHYS:7760: General Relativity and Cosmology (Spring 2015), graduate level, grader
- PHYS:7740: Quantum Field Theory (Fall 2014), graduate level, grader
- PHYS:1702: Physics I Lab (Fall 2014), freshman level, physics majors
- PHYS:1611: Introductory Physics I Lab (Summer 2014), introductory level
- ASTR:1771: General Astronomy Lab (Fall 2013, Fall 2012, Fall 2010 (Lead TA)), freshman
  level, astronomy majors
- PHYS:1511: College Physics I Lab (Summer 2013), introductory level
- ASTR:1772: General Astronomy II Lab (Spring 2013, Spring 2012, Spring 2011, Spring 2010), freshman level, astronomy majors
- ASTR:1070: Stars, Galaxies, and the Universe Lab (Spring 2013, Fall 2012, Summer 2012, Fall 2011, Fall 2010 (Lead TA), Fall 2009), general elective
- ASTR:1079: Introductory Astronomy Lab (Spring 2013, Fall 2012, Summer 2012, Fall 2011, Fall 2009), general elective
- ASTR:7775: Special Topics in Astrophysics (Fall 2012), graduate level, grader
- PHYS:1612: Introductory Physics II Lab (Spring 2011), introductory level

Grinnell College, Lecturer

- PHY:132 Lab: General Physics II Lab (Spring 2014), science majors

Publications

Refereed Journal Articles

- S. Brensinger, K. Heitritter, V. G. J. Rodgers, K. Stiffler and C. A. Whiting, Dark Energy from Dynamical Projective Connections, Class. Quantum Grav. 37, no. 5, 055003 (2020)

- R. Terrisse, D. Tsimpis and C. A. Whiting, D-branes and non-Abelian T-duality, NPB 947, 114733 (2019)
- L. A. Pando Zayas, D. Tsimpis and C. A. Whiting, Supersymmetric IIB background with AdS4 vacua from massive IIA supergravity, Phys. Rev. D 96, no. 4, 046013 (2017)
- L. A. Pando Zayas, V. G. J. Rodgers and C. A. Whiting, Supergravity solutions with AdS4 from non-Abelian T-dualities, JHEP 1602, 061 (2016)
- N. T. Macpherson, C. Núñez, L. A. Pando Zayas, V. G. J. Rodgers and C. A. Whiting, Type IIB supergravity solutions with AdS5 from Abelian and non-Abelian T dualities, JHEP 1502, 040 (2015)
- B. K. Button, L. Rodriguez, C. A. Whiting and T. Yildirim, A Near Horizon CFT Dual for Kerr-Newman-AdS, Int. J. Mod. Phys. A 26, 3077 (2011)
- C. A. Whiting, S. R. Spangler, L. D. Ingleby and L. M. Haffner, Confirmation of a Faraday Rotation Measure Anomaly in Cygnus, Astrophys. J. 694, 1452 (2009)
- L. D. Ingleby, S. R. Spangler and C. A. Whiting, Probing the Large Scale Plasma Structure of the Solar Corona with Faraday Rotation Measurements, Astrophys. J. 668, 520 (2007)

Conference Proceedings

- S. R. Spangler and C. A. Whiting, Radio Remote Sensing of the Corona and the Solar Wind, IAU Symp. 257, 529 (2009)

Technical Reports

- Whiting, Catherine A., Spangler, Steven R., EVLA Memorandum 136 (2009), http://www.aoc.nrao.edu/evla/memolist.shtml

Research Presentations

Invited Talks

- "Cosmological Inflation from Projective Gravity," Physics Seminar, Department of Physical and Environmental Sciences, Colorado Mesa University, September 3, 2020
- "D2 Brane Solutions of Supergravity and non-Abelian T-duality," Nuclear and Particle Physics Seminar, Department of Physics and Astronomy, University of Iowa, April 2018
- "New AdS Supergravity Backgrounds from non-Abelian T-dualities," Latin American Conference on High Energy Physics: Particles and Strings II, Havana, Cuba, July 2016
- "Non-Abelian T-duality and AdS/CFT," Mandelstam Institute for Theoretical Physics Seminar, University of the Witwatersrand, South Africa, April 2016
- "Type IIB Supergravity Backgrounds via Non-Abelian and Abelian T-Dualities" Mexicuerdas, Universidad de Colima, Colima, Mexico, June 2014
- "Non-Abelian T-duality and String Theory," Grinnell College Physics Seminar, Grinnell College, IA, April 2014

Contributed Talks

- "A New Supersymmetric IIB Background with AdS4 from Massive IIA," The First Mandelstam Theoretical Physics School and Workshop: Recent Advances in AdS/CFT, Durban, South Africa, January 2017

- "NS5 Branes on the Resolved Cone Over Y p;q," American Physical Society April Meeting, Denver, CO, April 2013
- ""Confining" Geometries Dual to Strongly Coupled Field Theories," Miami 2012 Conference, Ft Lauderdale, FL December 2012
- "NS5 Branes on the Resolved Cone Over Y p;q," Midwest Theory Get Together Conference, Argonne National Lab, September 8, 2012

Poster Presentations

- "NS5 Branes on the Resolved Cone over Y^{pq}," Catherine Whiting, V.G.J. Rodgers, E. Caceres, L. Pando Zayas, L. Rodriguez, Meeting of the Division of Particles and Fields of the American Physical Society, Brown University, 2011
- 'Radio Remote Sensing of the Solar Corona with the EVLA," Catherine Whiting and S.R. Spangler, American Astronomical Society Meeting 215, 2010
- 'Faraday Rotation Measure Anomaly due to the Cygnus OB1 Association," Catherine Whiting, S.R. Spangler, L.D. Ingleby, M.L. Haffner, American Astronomical Society Meeting 211, 2008
- "VLA Imaging of Cygnus X-3 Jets at 8.5 GHZ," Whiting, Catherine A., Rupen, M., Mioduszewski, A., American Astronomical Society Meeting 209, 2007

Awards and Honors

- Outstanding Teaching Assistant Award, University of Iowa, 2013
- Meshkov Award (University of Miami Software Award), 2012
- Best Theory Poster, 3rd Place Poster (overall), American Physical Society Division of Particles and Fields Meeting, 2011
- Barry M. Goldwater Scholarship, 2007
- Bill and John Fenton Scholarship, University of Iowa, 2006
- Myrtle K. Maier Scholarship in Physics and Astronomy, University of Iowa, 2006
- Strayer-Rairden Scholarship in Physics and Astronomy, University of Iowa, 2004

Grants

- Colorado Dept. of Higher Ed, $9600 (awarded 2021), "Developing and Implementing Open Education Resources (OER) Materials for GT-Pathways Introductory Physics Courses (PHYS 111, 112, 131, 132) at Colorado Mesa University," Youngmin Kim (PI), Brian Hosterman (Co-PI) and Catherine Whiting (Co-PI)
- Summer Research Apprenticeship, $3520 each (awarded to Muhammad Abdullah and Muhammed Hamza Kalim), Faculty Scholarship Committee, Bates College, Summer 2020
- Stipend ($3000) to assist development of introductory physics course aimed at physics majors, Bates College, Howard Hughes Medical Institute (HHMI) Inclusive Excellence Grant, 2019-2020
- Summer Research Apprenticeship, $3520 (awarded to Yehe Yan), Faculty Scholarship Committee, Bates College, Summer 2019

Service

Service to CMU

- Member of 2020-2021 Chemistry Tenure Track Search Committee
- Member of Student Showcase Committee representing the Department of Physical and Environmental Sciences
- Member of 2020 TRiO STEM Navigator Hiring Committee

Peer Review

- Reviewer for American Journal of Physics, 1 article

Research Advising

- Calvin Bavor, senior research, summer research, Colorado Mesa University, May 2021-
- Nicholas Harshman, senior research, Colorado Mesa University, August 2020- August 2021
- Eisho Takatsuji, junior undergraduate, Hoffman Fellowship, Summer research, Bates College, May-July 2020
- Muhammed Hamza Kalim, freshman undergraduate, Summer Research, Bates College, May-July 2020
- Muhammad Abdullah, sophomore undergraduate, Summer research, Bates College, May-July 2020
- Yehe Yan, Senior Thesis, Bates College, Fall Semester 2019
- Yehe Yan, junior undergraduate, Summer Research Apprentice, Bates College, July-August 2019
- Biruk Chafamo, freshman undergraduate, Summer Research Fellow, Bates College, June-August 2019
- Xiaole Jiang, sophomore undergraduate, Summer Research Fellow, Bates College, May-July 2019
- Godefroy Griva Bissouta, Master's student, African Institute for Mathematical Sciences Cameroon, Masters Essay: "Tests of General Relativity with Gravitational Waves Observations" April-May 2018

Miscellaneous Service

- Summer Research Program, Grad School Information Lunch Panelist, Bates College, June 2019
- Theory group Journal Club Organizer, School of Physics, University of the Witwatersrand, South Africa, 2016-2018
- External Examiner, Undergraduate Honours Physics Project (PHY 700), Department of Physics, University of Pretoria, Pretoria, South Africa, 2016

Training Presentations

- "Teaching Techniques: How to be Effective in Front of the Classroom," New T.A. Training, University of Iowa, Department of Physics and Astronomy, August 2014

- “Best Practices in Tutoring”, Campus Tutor Training Workshop, TRiO Student Support Services, University of Iowa, August 2012

Participation at Pedagogical Conferences

- Pedagogy Nuts & Bolts Workshops for new faculty, Bates College, Lewiston, Maine, September - October 2019
- Pedagogy Matters Conference, Bates College, Lewiston, Maine, August 23, 2019
- May Conference, Let One Idea Spark Another: The Pedagogy of the Seminar, Bates College, Lewiston, Maine, May 10, 2019
- April Conference, Development and Use of Open Educational Resources in Higher Education, Bates College, Lewiston, Maine, April 26, 2019
- CUREs (Course-Based Undergraduate Research Experiences) Workshops, Bates College, Lewiston, Maine, January - March 2019
- First ISLS (International Society of the Learning Sciences) Workshop, University of the Witwatersrand, Johannesburg, South Africa, February 12-13, 2018

Public Lectures

- “Black Holes,” Café Scientifique of Iowa City, April 2014
- “Dark Matter,” Eastern Iowa Observatory and Learning Center, July 2013
- “Big Bang! A History of the Universe,” University of Iowa Lifetime Enrichment Adult Program (LEAP) Course Instructor, Summer 2013
- “Black Holes,” Eastern Iowa Observatory and Learning Center, August 2012 Outreach

Public Outreach

- Tiger Cub Scouts Virtual Astronomy ‘The Sky is the Limit’ Meeting, January 27, 2021
- High School Student Job Shadowing Mentor, National Institute for Theoretical Physics, University of the Witwatersrand, South Africa, July 2017
- University of Iowa Physics Department outreach group, Hawkeyes on Science, numerous events, 2007-2015
- University of Iowa Department of Physics and Astronomy Public Demonstration Shows, yearly, 2007-2015
- North Tama Elementary School Mars Rover STEM Day, North Tama, IA, February 2012

Appendix H

CURRICULUM VITAE (Resume), 2020

Name: Anwar Yunas SHIEKH, Ph.D.

Citizenship: American (since May 2006); British born

e-mail: ashiekh@coloradomesa.edu

Web Page: sites.google.com/site/anwarshiekh/Home

Office phone: (980) 248-1649

Address: Colorado Mesa University
Grand Junction
Colorado, 81501

WORKING EXPERIENCE

Aug. 2010 – Present
Physics Instructor
Colorado Mesa University

Jan. 2002 – July 2010
Physics Instructor
Dine College

Feb. 2001 - Dec. 2001
Supervisor of the Test Development Group
Wolfram Research (the creators of Mathematica)

Nov. 1997 - Feb. 2001
Lead Software Quality Assurance Engineer, Wolfram Research.

Oct. 1989 - Oct. 1997
Researcher, High Energy Physics Group and Computer
Support, Scientific Computing Section.
International Centre for Theoretical Physics
Trieste
Ita

-Postdoctoral-

Nov. 1988 - Oct. 1989
NSERC
Postdoctoral Fellow
Department of Physics

University of Waterloo
Waterloo, Ontario
Canada

Jan. 1987 - Nov. 1988
Postdoctoral Fellow
High Energy Physics Group
International Centre for Theoretical Physics
Trieste
Italy
(1987: under scholarship from the Royal Society, London;
1988: under support from ICTP)

UNIVERSITY EDUCATION

Ph.D. 1983-86 Theoretical Physics
Imperial College, London University, London, England
Thesis title: Topics in Path Integration
(Supervisor: Professor C. J. Isham)

D.I.C. 1983-84 Mathematical Physics
(Diploma of Imperial College, Master's equivalent)
Imperial College, London University, London, England

B.Sc. 1980-83 Physics with First Class Honors (~top 5%)
Imperial College, London University, London, England

B.Sc. 1977-80 Mechanical Engineering with First Class Honors (~top 5%)
Imperial College, London University, London, England

AWARDS, RECOGNITION and SCHOLARSHIPS

2000
Recognized by the U.S. government as an alien of extraordinary ability.

1988-1989
NSERC (National Science and Engineering Research Council, Canada)
postdoctoral fellowship

1986-1987
Royal Society postdoctoral fellowship

1983-1985
SERC (Science and Engineering Research Council, England)

postgraduate grant

1977-1980
SERC (British) undergraduate grant

ASSOCIATESHIPS

Associate of the City and Guilds Institute
Associate of the Royal College of Science

SIDE INVOLVEMENTS

Academic
2003
Proposed, designed and built a Wi-Fi system for Dine College campus (included the construction of a 30' repeater tower)
1986
Set up and taught a microprocessor laboratory project for final year undergraduate students at Imperial College, London, England.

Industrial
1999
Helped the company 'Always Thinking' get the X10 software 'Thinking Home' working on the Mac for the X10 radio transmitter.

1995
Wrote a couple of articles for the New Gale Encyclopedia of science.

SUMMARY

Research in Theoretical Physics
My research is focused on mathematical methods in physics.

ICTP (International Center for Theoretical Physics)
Worked part time supporting the scientists, specializing in computer algebra support; hence the natural move to Wolfram Research when entering industry.

Wolfram Research, Inc.
Spent the 4 years earning my Green Card as a Lead Engineer in the Software Quantity Assurance department, where my knowledge of mathematics was usefully employed. Developed and documented internal quality assurance procedures on the internal Web site. Did some programming and research that shipped with the then current version.

Supervised a small team (about half a dozen people) that composed the test development group.

PUBLICATIONS over 450 citations altogether (http://scholar.google.com/)

- *Quantum Bit Error Avoidance.,*
  Journal of Applied Mathematics and Physics, 6, 2382, 2018
  {arXiv:1209.2113}

- *Approaching the event horizon of a black hole.*
  Adv. Studies Theor. Phys., Vol. 6, 2012, no. 23
  {arXiv:1209.2113}

- *Operator Regularization of Feynman Diagrams at multi-loop order.*
  Can. J. Phys., 89, 1149, 2011
  {arXiv:1006.1806}

- *Operator Regularization of Feynman Diagrams at one-loop order.*
  Can. J. Phys., 89, 289, 2011
  {arXiv:1006.1806}

- *Quantum Destructive Interference*.
  Electr. Jour. of Theor. Phys., 19, 43, 2008
  [arXiv:0808.1139]

- *The Quantum Interference Computer: error correction and an experimental proposal.*
  Int. Jour. of Theo. Phys., 47, 2176, 2008
  [arXiv:quant-ph/0611052], [arXiv:0704.2033]

- *A Review of Leading Quantum Gravitational Corrections to Newtonian Gravity.*
  (with Arif Akhundov)
  Electr. Jour. of Theor. Phys., 17, 1, 2008
  [arXiv:gr-qc/0611091]

- *The Role of Quantum Interference in Quantum Computing*.
  Int. Jour. of Theo. Phys., 45, 1653, 2006.
  [arXiv:cs.CC/0507003]

GAP
This gap in the publication list was when in industry (to earn the Green-Card).
GAP

- *Gravitational interaction to one loop in effective quantum gravity.*
  (with Stefano Bellucci and Arif Akhundov)
  Phys. Letts. B, 395 (1997) 16.

- *Gravity Quantized (The High-Tension String).*
  (with Stefano Bellucci)
  Invited plenary talk at the XX International Workshop on
  High Energy Physics and Field Theory, Protvino, Russia, June 1997.
  Eds. I.V. Filimonova and V.A. Petrov
  (Published in the proceedings, page 130-)
  [arXiv:gr-qc/9701065]

  Can the Equivalence Principle Survive Quantization?
  Invited plenary talk at the International Workshop on AntiMatter,
  Gravity and AntiHydrogen Spectroscopy, Molise, Italy, May 1996.
  (Published in the proceedings)
  Hyperfine Interactions 109 (1997) 105-
  [arXiv:gr-qc/9606007]

- *Is there no quantum form of Einstein Gravity?*
  Invited plenary review at the XIX International Workshop on
  High Energy Physics and Field Theory, Protvino, Russia, June 1996.
  Eds. V.A. Petrov, A.P. Samokhin and R.N. Rogalyov
  (Published in the proceedings, page 171-).
  [arXiv:gr-qc/9607005]

- *Quantizing Orthodox Gravity.*
  Can. J. Phys., 74, 172, 1996.
  [arXiv:hep-th/9307100]

- *Quantum Canonical Transformations. Consistent quantization and the Path Integral.*
  Invited talk at the XVIII International Workshop on
  High Energy Physics and Field Theory, Protvino, Russia, June 1995.
  Eds. V.A. Petrov, A.P. Samokhin and R.N. Rogalyov
  (published in the proceedings, page 311-).

- *Quantum Canonical Transformations revisited.*
  J. Math. Phys., 36, 6681, 1995.
  [arXiv:hep-th/9411199]

- *The Perturbative Quantization of Gravity.*
  Invited talk at the Poincare conference in Protvino, Summer 1994.
  Problems in High Energy Physics and Field Theory,
  Proceedings of the XVII workshop,
  Eds. A.P Samokhin and G.L. Rcheulishvili.
  (published in the proceedings, page 156-).
  [arXiv:hep-th/9407159]

- *Finite Massless Quantum Field Theory.*
  Can. J. Phys., 70, 463, 1992.

- *Does Nature place a Fundamental Limit on Strength?*
  Can. J. Phys., 70, 458, 1992.

- *Deriving the Path Integral from the Operator Formalism*
  (a new view on an old problem).
  Lectures on Path Integration: Trieste 1991,
  Eds. H. Cerdeira et al., World Scientific, 1993, p 563-.

- *Force on a Charged Particle Orbiting Around a Kerr-Newman Black Hole.*
  (with S. Chakrabarti)
  Proceedings of the Sixth Marcel Grossmann meeting on
  General Relativity, Kyoto 1991,
  Eds. Humitaka Sato and Takashi Nakamura,
  World Scientific, 1992, p 1360-.
  [arXiv:astro-ph/9211005]

Information Loss down a Black Hole.
(with S.C.Lee)
Gen. Rel. Grav., 23, 81, Jan, 1991.

- *Classical and Quantum Properties of Two-Dimensional Black Holes.*
  (with R.B. Mann and L. Tarasov)
  Nucl. Phys. B., 341, 134, Sept, 1990.

- *Zeta-Function Regularization of Quantum Field Theory.*
  Can. J. Phys., 68, 620, July-August, 1990.

- *Deriving the path integral from the operator formalism.*
  Can. J. Phys., 68, 428, April-May, 1990.

- *The trivialization of constraints in quantum theory.*
  J. Math. Phys., 31, 76, Jan, 1990.

- *Canonical Transformations in Quantum Mechanics, (a canonically invariant path integral)..*
  J. Math. Phys., 29, 913, 1988.

- *Wedges I.*
  (with C. DeWitt-Morette, S. G. Low, and L. S. Schulman)
  Found. Phys., 16, 311, 1986, a festschrift for J. Wheeler.

- *Calculation of Non-relativistic scattering of Charged scalar particles from a classical Aharonov-Bohm solenoid without an Explicit Gauge Choice, (a canonically invariant path integral).*
  Ann. Phys., 166, 299, 1986.

COURSES TAUGHT

- **Physics**
  Modern Optics
  Algebra based Physics (College Physics)
  Introduction to Astronomy
  Survey of Physics
  Calculus based Physics (University Physics)

- **Engineering**
  Introduction to Engineering

- **Mathematics**
  Calculus
  Pre-Calculus
  Discrete Mathematics
  Algebra
  Developmental mathematics

- **Computing**
  Computer Algebra/Mathematics
  LaTeX typesetting
  Developed a microprocessor Lab for Physics students

JARROD SCHIFFBAUER

School Address
Dept. of Physical and Environmental Science,
223K Wubben Hall
Colorado Mesa University
Grand Junction, CO 81501
jschiffbauer@coloradomesa.edu

Home Address
607 N. 6th. St.
Grand Junction, CO 81501
(304) 435-2525
jarrod.schiffbauer@gmail.com

EDUCATION

PhD, Theoretical Physics — August, 2011
West Virginia University, Morgantown, WV
THESIS - Nanocapillary membrane devices: a study in electro-kinetic transport phenomena

Master of Science, Theoretical Physics — November 2001
Ohio University, Athens, OH
THESIS - Lost in Hilbert Space: An Entanglement Model of the Measurement Process in Quantum Mechanics

Bachelor of Science, Physics — August, 1998
Ohio University, Athens, OH

PROFESSIONAL EXPERIENCE

Colorado Mesa University, Grand Junction, CO — September 2020 -

Special Research Professor of Physics. Partial teaching and grant-funded position, teaching 12 credit hours per year and serving as Principle Investigator for funded research projects. Main responsibility as PI is establishing and leading an interdisciplinary research collaboration between researchers at three universities (Colorado Mesa, Central Washington, and Notre Dame) to study nanoscale modulation of transport properties at solid-fluid interfaces and applications. Related duties include serving as research mentor for undergraduate students, writing grant proposals, project reports, and manuscripts, and managing data archives.

Colorado Mesa University, Grand Junction, CO — August 2017 - August 2020

Visiting Assistant Professor of Physics. Instruction and grading of undergraduate Physics courses and laboratories (average of 12 credit hours per semester); supervision of two undergraduates in computational physics/engineering research projects. Courses taught include algebra/trigonometry-based introductory physics lectures and laboratories for non-majors, conceptual physics, modern physics, and advanced dynamics. Outside of regular duties and acting as research mentor for students, engaged in active publication and presentation, and grant-writing.

University of Notre Dame, South Bend, IN — January 2016 - August 2017

(Aerospace and Mechanical Engineering) Postdoctoral scholar under Tengfei Luo. Experimental and theoretical study of phase change and interfacial heat transfer near plasmonically-heated surface-group functionalized core-shell nanoparticles in water for applications at the water-energy nexus and in biomedicine. Developed procedure for tuning nanoparticle-solvent interfacial thermal

conductance using two-phase self-assembled monoloayers of thiols with different headgroups, performed electrochemical characterization of particles, and developed theoretical models for bubble nucleation at functionalized surfaces.

Technion- Israel Institute of Technology, Technion City, Israel February 2012 - July 2015
Mechanical Engineering Postdoctoral scholar under Gilad Yossifon, Theory, numerical modeling, and experimental studies of electro-kinetic transport in micro- and nanofluidic devices. Experimental work includes experience with DC and AC measurements (including electrochemical impedance spectroscopy,) clean-room training in basic photolithography techniques, and optical microscopy. Also supervising M.Sc. student research and participation in grant-writing, including a successfully funded Technion grant for a portable water desalination scheme.

N & R Engineering, Parma Heights, OH August 2008 - January 2009, Intermittent
Biological Engineering Part-time engineering sub-contractor (NASA-IMM project), Theory and modeling support for implementation of basic physical models for biomedical engineering applications into probabilistic risk analysis.

Grand Valley State University, Allendale, MI August 2002- May 2003

Visiting Lecturer, Physics Department. Teaching duties included both an inquiry-based and a workshop physics course for small-to-medium sized (20-30) non-major classes, instruction and course development for a small elective course on wave phenomena for non-majors, and instruction of laboratory sections (average 12 credit hours per semester.)

North Central State College, Mansfield, OH August 2001- May 2002

Lecturer, Physics Department. Duties included instruction and development two different non-calculus-based courses with laboratory activities, management of laboratory equipment and coordination of efforts with adjunct faculty.

REFEREED JOURNAL PUBLICATIONS

[31] *Novel electro-osmotic micromixer configuration based on ion selective microsphere,* J. Schiffbauer, G. Ganchenko, N. Nikitin, M. Alekseev, and E. Demehkin *manuscript accepted for publication in Electrophore-
sis*

[30] *Transport Regimes of Underdamped Brownian Particles in a Tilted Washboard Potential ,* T. Jiron, M. Prinster, and J. Schiffbauer, *manuscript in preparation for submission to Phys. Rev. E*

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[26] *Overlimiting current due to electro-diffusive amplification of the second Wien effect at a cation-anion bipolar membrane junction*, J. Schiffbauer, N.Y. Ganchenko, G.S. Ganchenko and E.A. Demekhin, Biomicrofluidics, **12**, 064107, (2018)

[25] *The Transient Response of Non-Ideal Ion Selective Microchannel-Nanochannel Devices*, N. Leibowitz, J. Schiffbauer, S. Park, and G. Yossifon, Phys. Rev. E., **97**, 043104 (2018)
[24] *Liquid phase stabilization versus bubble formation at a nanoscale-curved interface*, J. Schiffbauer, and T. Luo, Phys. Rev. E., **97**, 033106 (2018)

[23] *Effect of Cooling on Droplet Size in Supersaturation-Induced Emulsion*, S. Luo, J. Schiffbauer, and T. Luo, Phys. Chem. Chem. Phys.,**19**, 29855-29861,(2017)
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[21] *Diffusion Layer Formation Drives Zone Migration in Traveling Wave Electrophoresis* W. A. Booth, B. Edwards, K. Jo, A. Timperman, and J. Schiffbauer, Analyst, 9, 142 (2017)
[20] *Modes of Electrokinetic Instability for Imperfect Electric Membranes*, G. S. Ganchenko, E. N. Kalaydin, J. Schiffbauer, and E. A. Demekhin, Phys. Rev. E., 94, 063106, (2016)
[19] *Confinement Effects on Electroconvective Instability*, M.B. Andersen, K.M. Wang, J. Schiffbauer, and A. Mani, Electrophoresis, doi:10.1002/elps.20160039, (2016)
[18] *Effect of electric field non-uniformity on droplet coalescence*, S. Luo, J. Schiffbauer, and T. Luo, Phys. Chem. Chem. Phys., (2016)
[17] *Robust Ion Current Oscillations Under a Steady Electric Field: An Ion Channel Analog* Y. Yan, Y. Wang, S. Senapati, J. Schiffbauer, G. Yossifon, and H-C Chang,Phys. Rev. E 94, 022613 (2016)
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[15] *Universal Low-Frequency Asymptotes of Dynamic Conic Nanopore Rectifcation: An Ionic Nanofluidic Inductor* Y. Yan, J. Schiffbauer, G. Yossifon, and H-C Chang, J. Chem. Phys., 143, 224706 (2015)
[14] *Ion Current Rectification in Funnel-Shaped Nanochannels: Hysteresis and Inversion Effects* L. Rosentsvit, W. Wang, J. Schiffbauer, H-C Chang, and G. Yossifon, J. Chem. Phys.,143, 224705 (2015)
[13] *Probing space charge and resolving overlimiting current mechanisms at the micro-nanochannel interface* J. Schiffbauer, U. Liel, N. Leibowitz, S. Park, and G. Yossifon, Physical Review E, 92, 013001 (2015)
[12] *Extended space charge near non-ideally selective membranes and nanochannels* J. Schiffbauer, N. Leibowitz, and G. Yossifon, Physical Review E,92, 013002 (2015)
[11] *The influence of electric double-layer structure on the transient response of nanochannels* J. Schiffbauer and G. Yossifon, Physical Review E. 89, 053015 (2014)

[10] *Concentration-dependence of nanochannel impedance and the determination of surface charge* J. Schiffbauer, U. Liel, and G. Yossifon, Physical Review E 89, 033017 (2014)

[9] *Electrical Impedance Spectroscopy of Microchannel-Nanochannel Interface Devices*, Schiffbauer, J.,Park, S., Yossifon, G., Physical Review Letters, 110, 204504 (2013)
[8] *Role of Electro-osmosis in the Impedance Response of Microchannel-Nanochannel Interfaces*, Schiffbauer, J., Yossifon, G., Physical Review E. 86, 056309 (2012)

[7] *Electrokinetic Instability in Micro-channels*, Schiffbauer, J., Demekhin, E. A., Ganchenko, G., Physical Review E, 85, 055302(R) (2012)
[6] *Fabrication and Performance of a Travelling-Wave Electrophoresis System*, Jo, K.D., Schiffbauer, J.E., Edwards, B.E., Carrol, R.L., and Timperman, A.T., Analyst, 137, (2012)
[5] *Simultaneous separation and detection of cations and anions on a microfluidic device with suppressed electroosmotic flow and a single injection point*, Brent R. Reschke, Jarrod Schiffbauer, Boyd F. Edwards and Aaron T. Timperman, Analyst, 135, (2010)

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[3] *A Theoretical and Experimental Study of the Electrophoretic Extraction of Ions from a Pressure Driven Flow in a Microfluidic Device*, Reschke, B.R., Luo,H., Schiffbauer, J., Edwards,B.F., and Timperman, A. T., Lab on a Chip, (2009)

[2] *Mechanisms of pit formation at strained crystalline Si*(111)/*Si_3N_4*(0001) *interfaces: Molecular-dynamics simulations*, Bachlechner, M.E., Srivastava, D., Owens, E.T., Schiffbauer, J., Anderson, J.T., Burky, M.R., Ducatman, S.C., Gripper, A.M., Guffey, E.J., Ramos, F.S., Physical Review B, 74, (2006)
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Dependence of Potential and Ion Distribution on Electrokinetic Radius in Infinite and Finite-length Nanochannels,J. Schiffbauer, E. Fernandez, W. Booth, K. Kelly, B. Edwards, and A. Timperman, Proceedings from the COMSOL 2008 conference
Steady-state simulation of mono-valent ion distributions within a nanofluidic channel, W. Booth, J. Schiffbauer, J. Fernandez, K. Kelley, A. Timperman, and B. Edwards, Proceedings from the COMSOL 2008
conference

EXTERNAL FUNDING

[1] *NSF-Collaborative Research: Using molecular functionalization to tune nanoscale interfacial energy and momentum transport*, Status: Awarded, 24 months duration, Colorado Mesa University, $ 395,801

[2] *NSF-EAGER: Collaborative Research: Dynamics of Nanoparticles in Light-Excited Supercavitation*, Status: Awarded, 24 months, Colorado Mesa University, $ 34,551

[3] *COSINC (internal): Analysis of nanoscale/microscale domain composition and morphology in mixed selfassembled monolayers using Kelvin probe force microscopy.*, Status: Pending, Colorado Mesa University, $ 5,000 (approx. value in facility time.)

[4] *NSF-Collaborative Research: CyberTraining: Pilot: The Development of Reproducible Training Materials for STEM Students in the Rocky Mountain Advanced Computing Consortium (RMACC*, Status: Pending, Colorado Mesa University, $ 73,730

[5] *NSF-ISS: Collaborative Research: Individual and Collective Behavior of Active Colloids in Microgravity*, Status: Pending, Colorado Mesa University, $ 34,551

INVITED TALKS, HONORS, AWARDS, APPOINTMENTS, ETC.

Nominated to Sigma Xi November, 2020

Invited seminar at NIST-CNST April 2017

Recipient of ND Energy Postdoctoral Fellowship September 2016-2017

Session chair at APS-DFD session G14 Electrokinetics: Nanochannels, Surface Conduction, Concentration Polarization November 2015

Recipient of Lady Davis Technion Postdoctoral Fellowship September 2012-2014

Invited faculty seminar at West Virginia University, Dept. of Mechanical and Aerospace Engineering October 2012

Invited faculty seminar at Ben Gurion University Dept. of Solar Energy and Environmental Physics June, 2012

WVSGC-NASA graduate research fellowship June-November, 2006, June-November 2007, and June-July 2011

Recipient of WVU Physics Dept. Teaching Assistant work performance award March 2011

Invited participant in Israeli Science Foundation Research Workshop on Electrokinetic Phenomena in Nano-colloids and Nano-fluidics December 2010

Participant in SPS-sponsored Adopt-a-Physicist program October 2009

Certificate of Recognition for Significant Contribution to the NASA Integrated Medical Module, part of the Human Research Project October 2009

Participant in NSF Doctoral Dissertation Enhancement Program June 2009

Sigma Pi Sigma Physics honors society Fall 2005

NSF-funded participant in the 2004 NATO-ASI conference on nanomaterials September 2004

Rotter graduate teaching award recipient May 2004

CONTRIBUTED TALKS AND POSTERS

Overlimiting current due to electro-diffusive amplification of the second Wien effect at a cation-anion bipolar membrane junction, J. Schiffbauer, N.Y. Ganchenko, G.S. Ganchenko and E.A. Demekhin, AIP-TNADD Meeting 2018

Electrokinetic Response of Charge-Selective Nanostructured Polymeric Membranes, J. Schiffbauer, D. Li, F. Gao, W. Phillip, and H-C Chang, APS-DFD Meeting 2017

Non-equilibrium phase stabilization versus bubble nucleation at a nanoscale-curved interface, J. Schiffbauer, and T. Luo, APS March Meeting 2017

Non-equilibrium liquid phase stabilization and vapor bubble formation at nanoscale-curved solid-liquid interfaces, J. Schiffbauer, and T. Luo, Notre Dame-Purdue Symposium on Soft Matter and Polymers, 2016

Resolving Overlimiting Current Mechanisms in Microchannel-Nanochannel Interface Devices, G. Yossifon, N. Leibowitz, U. Liel, J. Schiffbauer, and S. Park, APS-DFD, 2015

Electrochemical characterization of over-limiting current in micro-nanochannel systems, J. Schiffbauer, ACS Colloids and Surface Science, 2015

Electrokinetic Instability, Geometric Confinement, and Overlimiting Conductance, J. Schiffbauer, M.B. Andersen, A. Mani, and G. Yossifon, APS-DFD, 2014

Concentration-Polarization, Electro-Convection and Colloid Dynamics in Microchannel-Nanochannel Interface Devices, G. Yossifon, N. Liebowitz, Y. Green,U. Liel, J. Schiffbauer, and S. Park, APS-DFD, 2014

Probing Space Charge and Resolving Overlimiting Current Mechanisms at the Micro-Nanochannel Interface Using Electrochemical Impedance Spectroscopy, N. Liebowitz, J. Schiffbauer, U. Liel, S. Park, and G. Yossifon, AiChE, 2014

Electrical Impedance Spectroscopy of Colloid-Nanoslot Interactions, J. Schiffbauer, S. Park, and G. Yossifon, AiChE, 2014

Electrokinetic Colloid and Micro-Vortex Dynamics in Heterogeneous Nano-Slot Devices, G. Yossifon, N. Liebowitz, Y. Green, J. Schiffbauer, and S. Park ,AiChE, 2014

Electrical impedance characterization of micro-nanochannel devices, J. Schiffbauer, U. Liel, S. Park, N. Liebowitz, and G. Yossifon, ACS Colloids and Surfaces, 2014

Electroconvection in Heterogeneous Permselective Systems, Y. Green, N. Leibowitz, J. Schiffbauer, S. Park, and G. Yossifon, ACS Colloids and Surfaces, 2014

Probing space charge and resolving overlimiting current mechanisms at the micro-nanochannel interface using electrochemical impedance spectroscopy, J. Schiffbauer, N. Liebowitz, U. Liel, S. Park, and G. Yossifon,, ELKIN 2014

Probing electrokinetics in microchannels and nanochannels with electrochemical measurements, J. Schiffbauer, S. Park, and G. Yossifon, APS-DFD 2013

Geometric Modulation of Electro-Osmosis of the Second Kind in Micro-Nanochannel Interface Devices, G. Yossifon, N. Leibowitz, Y. Green, J. Schiffbauer, and S. Park, APS-DFD 2013

Transient response of the micro-nanochannel interface near the overlimiting transition, J. Schiffbauer, N. Leibowitz, S. Park, U. Liel, and G. Yossifon, BIFD 2013

Transient response of the micro-nanochannel interface: effects of fluid-flow, space charge, and non-ideal selectivity, J. Schiffbauer, S. Park, U. Liel, and G. Yossifon, AMN 2013

Transient response at the microchannel-nanochannel interface: chronopotentiometry, chronoamperometry, and electrochemical impedance , J. Schiffbauer, Y. Green, S. Park, and G. Yossifon, APS-DFD 2012

Role of Electro-Osmosis in Microchannel-Nanochannel Impedance Response J. Schiffbauer and G. Yossifon, AiChE Annual Meeting 2012

Computational modeling of traveling wave electrophoresis, R. Correll, J. Schiffbauer, and L. Carroll, APS March Meeting 2012

Fluidic rectification due to asymmetric concentration polarization at nano-microfluidic interface, J. Schiffbauer, K. Reschke, B. Zaltzman, B. Edwards, I. Rubinstein, W. Booth, and A. Timperman, APS March Meeting 2010

Anomalous analyte dispersion at microchannel-nanocapillary membrane interfaces, J. Schiffbauer, K. Kelly, W. Booth, J. Fernandez, A. Timperman, and B. Edwards APS March Meeting 2009
Traveling-wave electrophoresis for microfluidic separations B. Edwards, A. Timperman, L. Carroll, K. Jo, J. Mease, and J. Schiffbauer, APS March Meeting 2009

Simulation of Steady-State Non-Equilibrium Ion Distributions Within a Finite-length Nanofluidic Channel W. Booth, J. Schiffbauer, J. Fernandez, K. Kelley, A. Timperman, and B. Edwards, APS March Meeting 2009

Electrokinetic transport at a nanocapillary/microchannel interface, J. Schiffbauer, K. Kelley, B. Edwards, and A. Timperman, APS March Meeting 2008

Wave electrophoretic trapping and chaos, B. Edwards, L. Carroll, A. Timperman, J. Schiffbauer, and J. Mease, APS March Meeting 2008

Hydrodynamic flow in a microchannel due to nanocapillary membrane electro-osmotic flow, J. Schiffbauer, W. Booth, K, Kelley, B. Edwards, and A. Timperman, APS March Meeting 2009

Global and local properties used as analysis tools for molecular-dynamics simulations, M. Bachlechner, J. Anderson, D. Cao, R. Leonard, E. Owens, J. Schiffbauer, M. Burky, S. Ducatman, E. Guffey, and F. SerranoRamos, APS March Meeting 2006

A molecular-dynamics study of defects and failure mechanisms in strained heteroepitaxial interfaces, J. Schiffbauer and M. Bachlechner, APS March Meeting 2006

Lost In Hilbert Space: An entanglement model of the measurement process in quantum mechanics, J.
Schiffbauer, APS Ohio Fall Section Meeting 2001

Colorado Mesa University
B.S. Physics
Program Review
External Reviewer Report

Prepared by: Colin Inglefield
Professor and Chair
Department of Physics and Astronomy
Weber State University

May 17, 2022

Prologue:

I wish to offer a sincere thanks to the members of the Physics Program and the Administration members of CMU who helped with this process. The Self-Study was clear and complete without being unnecessarily long. The thoughtful planning of my schedule allowed me to get as complete of a picture of the program as possible in the context of a one-day visit. This report is based on that Self-Study and the visit, which included meetings with faculty, students, alumni, administrators, and staff members, including visits to two classes. In some cases, I've supplemented that with material from the CMU webpages and the American Physical Society Statistical Research Center. I take full responsibility for any inaccuracies.

Commendations:

1. The program faculty justifiably pride themselves on teaching physics and preparing students in their classes for next-step success. The two courses I visited, a 100-level service course for a variety of majors and a 300-level major course, were both being taught at a high level, and students were actively engaged in both settings. The students and alumni I met with were very impressive.

2. Students and alumni reported a high level of satisfaction with the program in my conversations with them. There was a lot of pride in the rigor of the program and students' ability to compete with graduates from larger institutions at the next stage, whether that was graduate school or the private sector. Students felt that they were well-advised throughout their program without being coddled.

3. The capstone research projects and seminar series, which the faculty identified as "possibly our greatest strength" in the Self-Study is particularly impressive, given the limited number of faculty in the program and research space available.

4. The program's COVID response seems to have been in-line with that of the institution as a whole, and I can find no fault with it. The problems associated with the COVID crisis mentioned in the Self-Study (loss of laboratory learning experiences, loss of student community…) were essentially universal, as far as I can tell.

5. The faculty, including instructors and adjuncts, are all appropriately credentialed and very well qualified for their positions.

6. The program has a sustainable system of Assessment of Learning Outcomes in place with full faculty participation.

Curriculum

The BS, Physics program at CMU is relatively straightforward and follows national norms, with a notable emphasis on the capstone senior experience. In addition to University general education requirements, students must complete:

- 14 hours of "Foundation" courses at the 100 level. These include a 10-credit lecture/lab sequence of calculus-based introductory physics. This is the same sequence taken by a variety of science and engineering majors. Probably the most notable thing about the introductory courses at CMU is their relatively small class size, which I consider a positive attribute from a student perspective. I counted 25 students in the PHY 132 class I observed, which was taught at a high level at with plenty of student engagement,
- 44-45 hours of "Core" courses at the 200, 300, and 400 level. These include a laboratory course at the 200 and 300 level, and a standard slate of theory courses and supporting math courses. This group also includes the capstone research/seminar sequence, which is particularly strong and integral to the culture of the department,
- Additional elective courses in more specialized topics. My understanding is that these can only be offered based on sufficient demand.

The design of the program is current and appropriate for preparing students for next-step success. I am happy to see labs at the 100, 200, and 300 level required within the program; physics is an experimental science. The biggest issue I see (and this came up in my meeting with students and alumni) is maintaining sufficient enrollment in the program to be able to consistently offer upper division elective and "topics" courses. See the first item in my recommendations below.

Assessment

The program has assessed a set of seven Student Learning Outcomes (SLOs) across several levels in the degree program.

For example, at the 100 level they have used a standard, externally produced, tool the Force Concept Inventory test to assess fluency, where they have shown a "medium gain", an indication of successful implementation of learning strategies.

At the higher levels, assessment is done differently, probably because of a relative paucity of standard instruments and small class sizes making a statistical analysis less useful. Here they rely on the fact that specific courses, or assignments within courses, may tie directly to a particular SLO. For example, the "Information Literacy" SLO is assessed through an assignment where students have to find reference material for a laboratory report in PHYS 331. The "Communication" SLO was assessed for the seminar course, PHYS 494. In both examples, the assessment was based on student grades on the assignment/course. The value of that data is somewhat limited, meaning that they have only verified that students passed at some appropriate level. It's possible that they could do more evaluation of student gains in the PHYS 494 sequence, again just as an example and get more detailed and useful information.

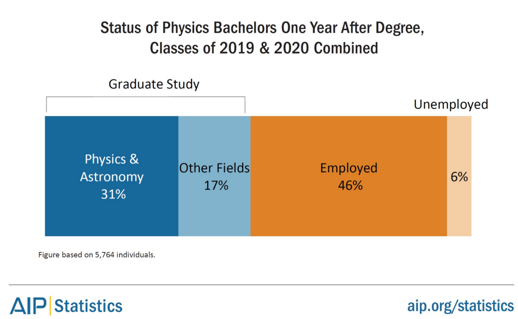
However, I have no specific recommendations for changes to the assessment program. What is in place is clearly sustainable and has the participation of faculty at all levels, which is most important.

Enrollment/Demand

There seems to be a general agreement that the program would function better with more students in the upper division courses. Current students and alumni both mentioned courses being canceled for lack of demand, although they were quick to point out that, through effective advising, nobody's graduation was postponed.

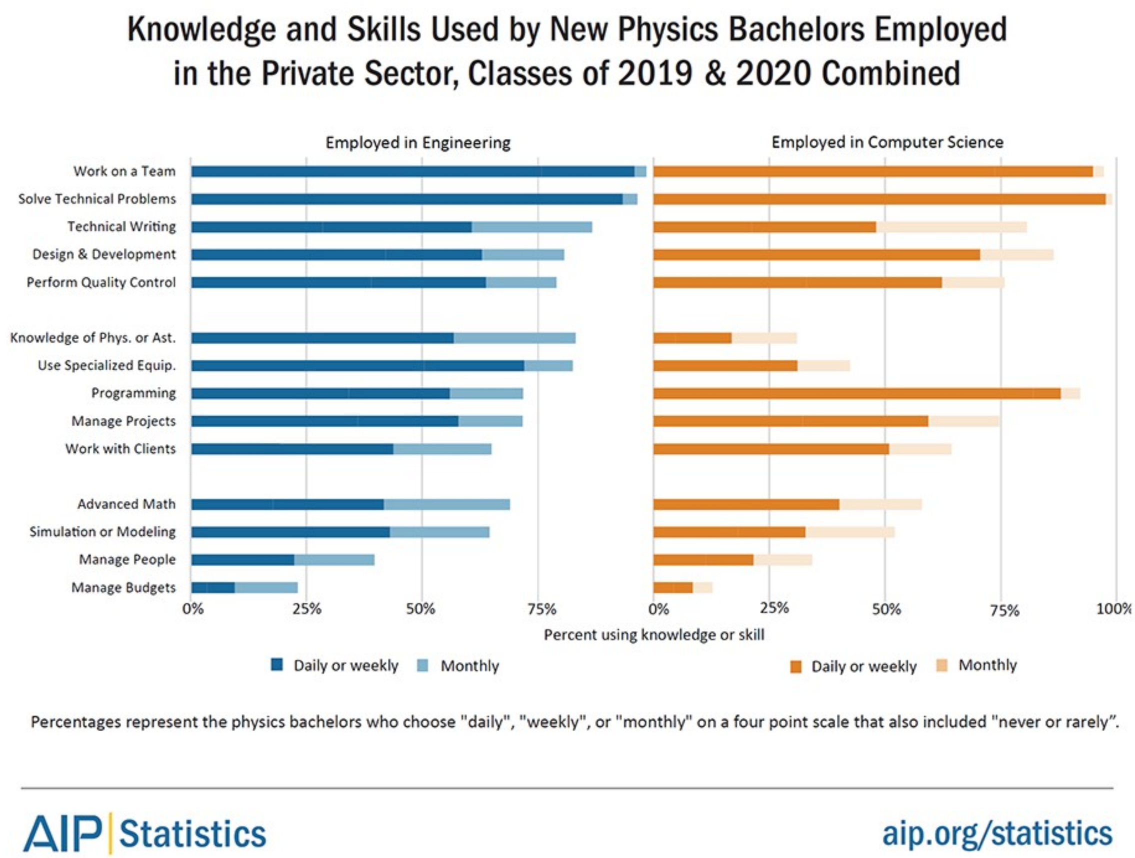
I've taken data from the American Institute of Physics Statistical Research Center (aip.org/statistics) to attempt to see how the program size compares to other programs regionally and nationally. If I look at just the most recent data (2019 and 2020) for size of the introductory physics program and number of graduates, there are certainly a number of comparable institutions to CMU.[1] The enrollment in introductory physics courses at CMU totals around 500 with about 5 graduates per year. The one Colorado institution considered a peer to CMU, CSU-Pueblo, has a smaller introductory program and smaller number of graduates, with a similar roughly 100:1 ratio of those. There are some programs in the state and peer institutions in the country, Metro State and Angelo State are examples, where the number of graduates is higher, relative to the size of the introductory programs. Those examples are a positive sign for potential growth, perhaps more physics majors can be "found" or recruited from CMU's existing 500-student-per-year introductory physics program.

In discussions with alumni and junior/senior students, their plans for and experiences after graduation appear to agree with national trends (below), with a sizable minority pursuing graduate education of some kind and the rest finding employment in a variety of fields. That is to say, physics graduate from CMU appear to have all the same opportunities as physics graduates nationally.



[1] https://www.aip.org/sites/default/files/statistics/rosters/PhysRost20.pdf and https://www.aip.org/sites/default/files/statistics/rosters/PhysRost19.3.pdf

The program's emphasis on a capstone project and presentation seems well-placed, considering data from recent graduates that rank problem solving, communication, and teamwork as particularly important next-step skills.



Support for the Program

The various administrative units that I met with all shared with me a positive view of the program and all seemed to have good working relationships with the program. The library and its collection were particularly impressive for the size of the institution. The legal/administrative issues with purchasing and IT support were understandably creating frustrations on both sides, but not to the level of creating dysfunction (see recommendation 4 below). Faculty from the program are actively participating in campus leadership (Assistant Vice President, Faculty Senate President…) indicating strong relationships between program faculty and the rest of campus.

Challenges/Recommendations

1. Recruiting. The program is struggling to attract a sufficient number of majors and/or students to justify running its upper-division courses. The lack of women students during the site visit was particularly striking. *I recommend the program faculty agree on a plan and goals for recruiting students to their upper-division courses.* I'll list some observations and suggestions, but the faculty "on the ground" are clearly best positioned to develop a strategy, and I don't mean for the items listed to be the only possibilities. With a smaller department, a plan that everyone is behind is critical, in my opinion. My thoughts are enumerated below, in no particular order.
    a. *Promote the Astronomy courses and opportunities available in the program*. My own experience is that an introductory course in astronomy (in your case, PHYS 101 *Elementary Astronomy*) can be a place to "find" majors. Promoting and showcasing opportunities to study astronomy within the department could attract students, and might attract a more diverse group of students.
    b. *Use alumni and their stories as recruiting tools*. It's clear from my discussions with alumni that they are a group with compelling success stories who are willing to take the time to help the department. I understand that some effort is already underway to create some short videos of alumni. The alumni I met were your fans, and they are perhaps an underused resource.
    c. *Work on relationships with high schools*. With local high schools, Mesa's reputation may be focused on its largest programs (i.e. Mesa is regarded as the school for students interested in nursing). I recommend you share your story with science teachers in the surrounding high schools, whom science-oriented students may approach with questions about where to go to college.
    d. *Work on relationships with community colleges.* The community college closely associated with CMU, Western Colorado Community College, seems to focus on "terminal" two-year degrees. However, a quick search of community colleges in the state indicates that several offer pre-engineering or "physics transfer" programs. It's critical that students, faculty, and advisors in these community college programs are aware of the possibility of completing a B.S. degree in physics at CMU. I recommend creating a brochure and/or website specifically for these students. The smaller class sizes and modest price tag at Mesa (compared to Colorado public flagships) could be particularly appealing to community college students.
    e. *Promote your minor*. I didn't meet any students pursuing a minor in physics and am under the impression that the program is relatively small. I noted however that your physics majors mentioned they were completing minors in mathematics, and that they viewed that minor as "low cost" to them, given the number of math courses already required for the physics major. Could you promote the physics minor more for students in particular majors (chemistry and applied mathematics come to mind)? Is there a way to incentivize those students?
    f. *Explore the possibility of a certificate in physics*. One of the challenges for the physics minor program is that students pursuing engineering degrees on the CMU campus are ineligible for the program, because the engineering program

operates as a satellite of the CU flagship campus. Could a certificate be a "work around" here? I'd suggest a certificate program include both experimental and theory courses, to justify it as in-part a "skills" certificate.

g. *Hire a tenure track faculty member in Physics Education Research (PER).* I suggest the department consider this avenue for their next national search. A faculty member with a scholarly interest and background in PER would enhance the vibrancy of the program and could attract education-oriented students to the major.
h. *Don't sacrifice rigor.* When a program suffers from low numbers, the question naturally arises about "streamlining" or reducing requirements for the program. In the case of the physics program at CMU, the high quality, rigor, and capstone programs are clearly part of the program identity and existing culture.

2. Management of Introductory Labs. *I recommend the program and department address the issue of management of the introductory labs*. Because there is only one room used for introductory labs to support the four introductory courses (PHYS 111, 112, 131, 132) the room must be reconfigured and new equipment set up multiple times per week. This is the job of nobody in particular and seems to frequently fall on whatever instructor is the first in a series to teach a particular lab. Some instructors appropriately expressed their frustration with this arrangement. A related problem is that there is nobody to help with lecture demonstrations for the introductory classes and no convenient way to set those up in advance. Thus, a combination of merely adequate space and no support staff results in an inefficient use of faculty time, especially when those faculty are so clearly interested in devoting time to working with majors on capstone projects. I can think of at least three options to address this problem, all would require institutional support. The first two came up naturally in my discussions during the visit.
   a. Option 1. *Add a staff member to manage labs*. A staff person could curate the equipment storage area, set out equipment for labs and demonstrations according to the schedule, and repair equipment where that made sense. This would be a tremendous benefit to the program faculty and students. To be viable as a full-time position, or close to that, the position might be shared with another program (Earth Science?).
   b. Option 2. *Add a full-time instructor to teach and manage labs*. I imagine a person with preparation at the level of a master's degree and with an experimental background could teach several lab sections and manage both the lab setup and equipment storage area. Someone in this position long-term would be especially beneficial for the laboratory program.
   c. Option 3. *Address this need with a tenure-track hire with an emphasis on PER.* This is the most radical and disruptive of the three options. A new faculty member with a scholarly interest in Physics Education Research (PER), particularly with an interest in learning in the introductory lab, could partially take over ownership of the lab program. This might seem less of a burden to a faculty member with a scholarly interest in that lab program. Such a faculty hire could also provide a range of new capstone projects for majors with an interest in

educational research, and thus attract a different, perhaps more diverse, set of students to the program, along the lines of the recruitment efforts discussed above. Is there a possibility of “upgrading” an existing full-time instructor line to a tenure-track line with a national search?

3. Advising. Academic advising is currently assigned essentially randomly by the department administrative specialist. She told me when a student comes in to declare a major in physics, she provides general information and then assigns an advisor from the department faculty list based on a rotation system. I realize this may be because of an institutional practice where all faculty are expected to take part in advising and are evaluated in that category. However, spreading advising out in such a way seems irregular and inefficient to me. *I recommend major advising be handled by one or two faculty members.* This seems more efficient, could result in development of best-practices for advising, and would ensure more consistency in advising.

4. Administrative support. In the self-study, the program appropriately voiced frustrations with the “inflexibility” of supporting units like Information Technology and Purchasing. This is a serious issue with the potential to affect faculty retention and progress toward tenure and promotion. I had the opportunity to discuss this with the CMU VP for Information Technology, and he seemed both aware of the issues and earnest in his desire to navigate the legal issues associated with software purchases in particular. *My recommendation here is that the program continue the discussions that are ongoing with these support services, but also seek advice from other state institutions about how these issues are being addressed elsewhere.*

5. Satisfaction of non-tenure-track faculty. In my meeting with instructors and adjuncts, they all were grateful for the academic freedom they had in designing and teaching their courses, but some felt they would like more input in their teaching assignments. There was some sense that students may view instructors as a “lower tier” compared to tenure-track faculty, making their jobs more difficult. *I recommend the program work on ways, both formal and informal, to more fully include instructors and adjuncts in the program.*

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