Appendix 3:
Request for Curriculum Change

UNC CH & NCSU
Joint Department of Biomedical Engineering – Master of Science

This request has been reviewed and approved by the appropriate campus committees and authorities.

Endorsed By:

Nancy L. Allbritton Nancy Allbritton MD, PhD 21 September 2017
Head, Department/Director of Graduate Program (Printed Name and Signature) Date

Recommended By:

Douglas S. Reeves Douglas S Reeves 21 September 2017
Chair, College Graduate Studies Committee (Printed Name and Signature) Date

Endorsed By:

Louis Martin-Vega 21 September 2017
College of Engineeiring - Dean (Printed Name and Signature) Date

Endorsed By:

William L. Roper 21 September 2017
School of Medicine - Dean (Printed Name and Signature) Date

Approved By:

Dean of the Graduate School (Printed Name and Signature) Date

Recommended By:

Dean's Council (Printed Name and Signature) Date

Approved By:

Executive Vice Chancellor and Provost (Printed Name and Signature) Date

Approved By:

(revised August 2015)

Joint Department of
BIOMEDICAL ENGINEERING

UNC CHAPEL HILL | NC STATE UNIVERSITY

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7 November 2017

Peter J. Harries, PhD
Interim Dean
The Graduate School
NC State University
1020 Main Campus Drive
Campus Box 7102
Raleigh, NC 27695

Subject: Request for Change in Curriculum – Master of Science Degree

Dear Dr. Harries,

On behalf of the UNC-CH NCSU Joint Department, please accept the attached Request for Curriculum Change.

Over the past several years, the Joint Department has made some considerable effort to effectively review its accomplishments and its positioning relative to its mission and strategies. These are briefly described below.

Mission:
to unite engineering and life sciences, health, and health care to improve lives

Strategies:
Education – train a workforce that can make important contributions to the health and well-being of the citizens of the state, nation, and world
Entrepreneurship – create new businesses in the state that can compete globally
Research – provide translation of cutting edge research to licensing and commercialization

From our in-depth, broad ranging analysis including students, alumni, faculty, administration, and external advisors, we seem to be doing well in education and research. At the BS level our students are highly regarded for their knowledge and strongly pursued by industry. At the PhD level our programs have grown and are widely regarded by our peers as exceptional.

Entrepreneurship and translation of research to licensing and commercialization appear to be areas of opportunity. We believe the Masters' Degree presents the most appropriate leverage point for us by changing the curriculum from one focused on research and thesis preparation to one emphasizing professional practice. When comparing ourselves to peer groups at GIT, Johns Hopkins, Michigan, Rice,

MIT, Stanford, UC – Berkeley and others, we have observed an obvious shift from the traditional MS to intense programs with professional practice focus.

Initially, the Joint Department approached this opportunity by utilizing the Professional Science Masters pathway. After approval of our Request to Plan at UNC CH and NC State and with the review and advice from the two Provost Offices, we believe the modification of the MS curriculum to be most appropriate.

Consequently, we seek approval for the curriculum changes addressed in the attached proposal/request. We believe these changes will (a) increase the number of MS graduates; (b) provide candidates with the knowledge, skills, experiences, and capabilities necessary to succeed and to lead in an increasingly highly competitive industry; while (c) enhancing the value of our MS consistent with the Joint Department Mission and Strategies.

Respectfully submitted,

Zhen Gu, Ph.D.
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Joint Department of Biomedical Engineering | Pharmacoengineering Track
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cc:
Dr. Nancy Allbritton
Dr. B. D. Barnes
Dr. Duane Larick
Dr. Dwayne Pinkney

Formal Proposal for Curriculum Change

UNC CH NC State University Joint Department of Biomedical Engineering

Master of Science Degree

7 November 2017

Program Curriculum Changes (except name changes)
https://grad.ncsu.edu/faculty-and-staff/program-development/program-curriculum-changes/
Departments/programs that wish to make curriculum changes such as changes in degree requirements including courses, and credits, for an existing graduate degree program must submit a formal proposal for approval by the Graduate School. The proposal should include the following:

- **Background: An overview explanation of why the change(s) is being proposed; how will it improve the degree program.**

A. Why is the change being proposed?

The Mission of the Joint Department is ***to unite engineering and life sciences, health, and health care to improve lives*.**

1. To accomplish this mission three strategies are pursued.
    a. Education – train a workforce that can make important contributions to the health and well-being of the citizens of the state, nation, and world.
    b. Entrepreneurship – create new businesses in the state that can compete globally.
    c. Research – provide translation of cutting edge research to licensing and commercialization.
2. Currently the Joint Department offers three degrees (number of recent graduates in parentheses): BS (102), MS (8), and PhD (16). The current MS and PhD are traditional research/thesis in nature.
3. By comparison with several top 10 BME programs (as identified by US News & World Report) that the Joint Department has identified as belle weathers: Johns Hopkins, Georgia Tech, Duke University, UC San Diego, UC Berkeley, Rice, Stanford, University Washington – Seattle, University of Michigan – Ann Arbor and selected others (University of Texas, Texas A&M, Washington University – St. Louis, WFU/VPI, University of Wisconsin and Purdue) the proportion of Joint Department MS graduates appears to be too small at about 6% compared to an average of comparable programs of approximately 17%. Within the College of Engineering the average proportion of masters' in recent years has been 37%.
4. As demonstrated in Table 1 below, the Joint Department is unique in its MS focus compared to its comparison peer group.

Table 1 – MS Program Offerings
Joint Department MS Offerings Compared to Peers

No.	Institution	MS Research with Thesis 21+ months	MS or similar Non-thesis 18+ months	BS/MS (5th year program) 9 to 12 months	MS or similar Non-thesis 12 months
1	Duke	yes	Master of Engineering		
2	GIT	no			MS in Biomedical Innovation & Development
3	Johns Hopkins	yes			MSE – Center Bioengineering Innovation and Design
4	MIT	yes in certain cases		Master of Engineering in Biomedical Engineering	
5	**Joint Department UNC CH NC STATE**	**yes**			
6	Purdue	yes	MS – non-thesis with Industry Immersion	BS/MS in Biomedical Engineering	MS – non-thesis
7	Rice	no	Master of Bioengineering (MBE) – Applied Bioengineering		Master of Bioengineering (MBE) - Global
8	Univ of Washington - Seattle	yes		BS/MS	Master of Applied Bioengineering
9	Stanford	no	MS Bio-Design		MS – Bioengineering
10	Texas A&M	yes	Master of Engineering (Clinical Immersion and Product Innovation)		Master of Engineering (Industrial Immersion and Product Engineering)
11	U Mich Ann Arbor	yes (non-PhD)	MS – Design – 21	BSE/MSE	MS – Design - 12
12	U of Wisc - Madison	yes	BS BME @ U of W - MS		
13	UT Austin	no	MSE (non-thesis – 30 hours) MSE (thesis 6 + 24 hours)		
14	UVA	yes	Master of Engineering		
15	VPI/WFU	yes			
16	Wash University – St. Louis	X	MS BME (non-thesis)		Master of Engineering Biomedical Innovation

In general, BME MS offerings are moving to shorter time frames and to more professional practice oriented offerings.

5. Over the 10-year period from 2005 through 2014, 770 individuals applied for the Joint Department MS research with thesis program; approximately 50% were judged to be qualified; 64 enrolled. This group was surveyed in 2016 to determine their area of work. 83% indicated professional practice as opposed to research. Based on the growth of practice oriented MS programs over this same time-period, one may postulate that a majority of those 300+ qualified candidates not matriculating in the Joint Department BME traditional, MS research/thesis program pursued professional practice oriented MS degrees.
6. The life sciences industry in North Carolina represents 5% of total employment; over 220,000 jobs; with average salaries exceeding $80,000; and representing a total economic impact in excess of $76 billion. Medicine, health, and health care are major contributors to this industry. Competition is intense. North Carolina faces substantial challenges to the retention of this status and continued growth in the sector. The most significant challenge, termed as a “rate-limiting” component, is the limited number of professionals with training and experience spanning life sciences, product development, commercialization, and financing.

The Bottom Line – The change is being proposed to prepare an increased number of MS students with the training, expertise, and practice oriented experience required to address the needs of the life science industry in North Carolina and beyond.

B. How will it improve the degree program?

The proposed curriculum changes will allow the Joint Department to accomplish the following.

1. Address the specific needs identified by professionals practicing healthcare innovation and entrepreneurship.
    i. The proposed curriculum changes will provide training and immersion experiences more reflective of professional practice, as related to innovation and entrepreneurship in healthcare, specifically emphasizing:
        1. Discovery or confirmation of needs;
        2. Design of innovative products and processes; and
        3. Development of working proof-of-concept prototypes.
    ii. Pedagogically, all delivery and work will be pursued in a team-based environment emphasizing both leadership and followership.
    iii. Faculty will perform their roles more reflective of that observed in successful start-ups and small innovative entrepreneurial organizations, i.e. more as mentors and coaches.
    iv. Candidates will become adept at working in networks by working in teams of short and long duration.
    v. Teams will be deeply immersed in the clinical and related manufacturing environments with the objective of identifying (or confirming) needs and developing viable, commercial solutions.
    vi. Courses will emphasize four areas of concentration: (a) discovery and design; (b) finance, accounting and business technology; (c) management and entrepreneurship; and (d) healthcare technology.
2. Provide a larger group of MS graduates with behavior and demonstrated performance prepared for current and future professional practice in the rapidly changing healthcare industry.
3. Enhance the opportunity for small teams of MS graduates to license healthcare related inventions or to form start-up companies.
4. Attract and matriculate candidates with a bias toward “Entrepreneurship.”

- **Proposed changes: List each proposed change and the specific rationale for that change.**

Overview: The proposed changes in curriculum are designed to provide skills and experiences necessary to cross-functionally integrate technology, design, business, and management in support of improving behavior and performance in delivery of health and health care while reducing costs. With an emphasis on translation of innovations, this will be accomplished, as illustrated in Figure 1 below, through a time-intense curriculum combining 37 semester hours of coursework (9 hours each of Design and Technology, 10 hours of Management, and six hours of Finance, Accounting, and Business courses) in combination with an intensive 520 person-hour experiential

practicum/internship (credited as three semester hours) in partnership with the UNC-SOM, UNC Healthcare, and other leading health and healthcare related organizations (e.g. for profit, not-for-profit, non-profit).

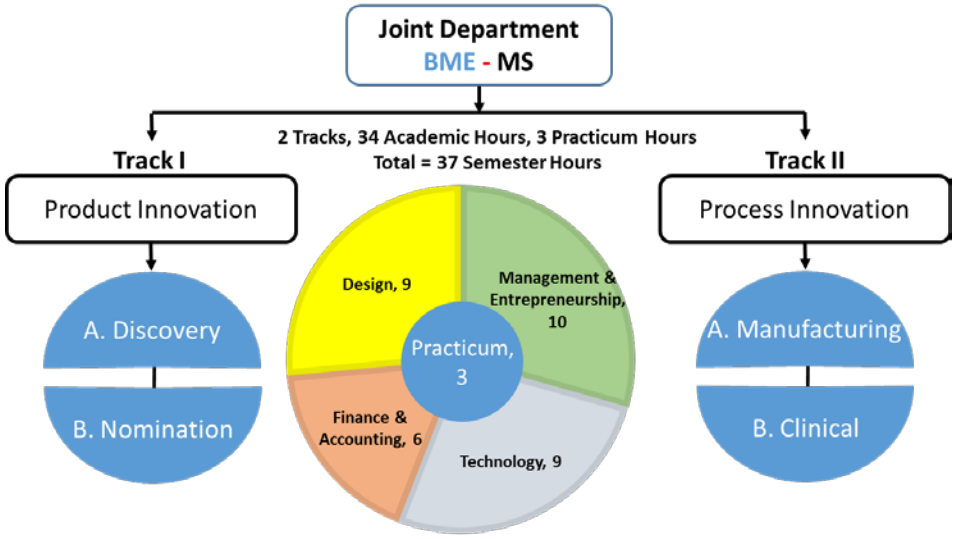

Figure 1: Conceptual Picture of BME MS

The 12-contiguous month program provides students a unique environment to focus on either Track I, product innovation or on Track II, process innovation. The goal is for students to receive high quality, interactive, cross-functional instruction and substantial practice-oriented mentoring in a real-world environment. The target audience includes those with previous engineering and/or STEM degrees with the career goal of leading in the integration of technology, design, management, and business to improve health and healthcare. Those successfully completing the degree will be awarded an MS degree upon the recommendation of the Joint Department. Effective with the approval of this Request for Curriculum Change, each matriculant's transcript will indicate completion of the terminal degree with concentration in healthcare innovation and entrepreneurship.

Duration: The proposed curriculum reduces time to degree from a traditional 21 calendar months to 12-contiguous months.

Facility Utilization: The proposed curriculum requires 30 to 50 candidates, progressing as a single cohort, to be fully engaged and utilizing classroom and working space from 8:00 AM to 5:00 PM each day throughout the summer, fall, and spring periods.

Service to North Carolina: Within the state there is no MS degree focusing on the professional practice of biomedical healthcare innovation and entrepreneurship. Annually, 20 to 30, qualified, applicants seeking such an MS degree (i.e. non-thesis, non-research) are turned away by the Joint Department for lack of the proposed curriculum. Currently these candidates must turn to out-of-state programs. Recent feedback indicates these unserved candidates are unlikely to return to

North Carolina. It is expected that these and others will take advantage of the revised curriculum once it is available, advertised, and promoted.

Future Research Degree Candidates: These candidates will be vetted through the current PhD admissions process. The research MS with thesis will no longer be offered after the beginning of the Fall 2017 semester.

- **Logistics: When is the change proposed to be effective?**
  First Session Summer School 2019

- **How will current students in the program be handled?**
  Current MS students will be informed and will complete their MS degree (http://bme.sites.unc.edu/research/) under the existing curriculum, with their assigned advisors, and consistent with current processes and procedures (including, upon acceptance/approval, continuation to the PhD program). Courses germane to those students currently admitted and seeking the research MS and for those admitted directly to the PhD program, will continue to be available into the foreseeable future, i.e. well beyond the initiation of the proposed curriculum for the non-research, non-thesis MS.

  Effective upon approval of this Request for Curriculum Change, those PhD students unable to complete their degree will be provided an MS, as appropriate, for their completed work during their last semester in the PhD Program. Their transcript will indicate specialization in one of five areas as identified by the Joint Department (http://bme.sites.unc.edu/research/): (1) imaging, (2) micro-devices, (3) pharmaco-engineering, (4) rehabilitation, (5) regenerative medicine. Over the past 5 years, on average, 1% (i.e. about 1 per year over the last five years) of PhD candidates matriculated in this manner. The impact is perceived as negligible.

- **Copy of Current Curriculum**
  Course requirements include a minimum of 30 semester hours: (Appendix 1 provides a listing of courses)
  1. BME Seminar (BME 802 / BMME 890) – each semester prior to graduation (except the semester prior to graduation): 3 hours
  2. Bio/Med: Graduate Biochemistry in the Fall semester *and* Systems Physiology in the Spring semester: 6 hours
  3. Engineering: 6 hours
  4. Graduate-level mathematics: 3 hours
  5. Graduate-level statistics: 3 hours
  6. Scientific/Technical Electives: 6 hours or more (with approval of advisor)
  7. Thesis research: minimum of 3 hours

- **Copy of Proposed Curriculum**
  Program Requirements and Curriculum
  A. Degree requirements:
     1. Total hours required - 37 Semester hours of graduate course work across five focus areas are required for the degree.

2. Below are listed the five key topical focus areas associated with the Request for Change in Curriculum. Table 2 links Focus and specific courses.
    i. Discovery and design – 3 course/9 semester hours
    ii. Finance, accounting, and business technology – 2 course/6 semester hours
    iii. Health and health care technology electives - 3 courses/9 semester hours
    iv. Management and entrepreneurship – 6 courses/10 semester hours
    v. Practicum experience – 3 courses /3 semester hours - Discovery, Design, and Development
        - Many non-thesis, non-research MS degrees require "0" credit hour individual projects and/or internships. In lieu of these, this program requires teams of 5 to 7 individuals to engage in coordinated, carefully managed immersion activities within the UNC SOM, UNC SOD, UNC SON, UNC School of Public Health, NCSU College of Veterinary Medicine, UNC Healthcare Facilities or Clinics, CVM-Animal Hospital or remote clinics, and/or selected partner manufacturing facilities. Team members should each budget a total of 520 person-hours for this work. The distribution of effort is shown in parentheses for each category of immersion. These activities are designed to provide candidate teams with the opportunities to ***discover (240 person-hours)*** and identify healthcare needs; to conceptually ***design (140 person-hours)*** new products and processes and to prepare shop drawings or value stream process models; and to ***develop (140 person-hours)*** detailed working proof-of-concept prototypes or process implementation plans. Much of the background for these activities will be provided in formal course work. However, it is important that candidates have the opportunity to interact with professionals in these areas at the time of immersion to improve their understanding, behavior, and performance. Consequently, about once per week topic specific seminars will be provided by subject matter practicing professionals to assist teams in their efforts.
        - Three Special Topic Practicum Seminars: composed of 12 one-hour required-attendance seminars (i.e. approximately one per week) by practicing innovation and entrepreneur professionals. Each is designed to be highly interactive and thought provoking as related to the emphasis topic for the period.
            - BME 691: Summer – Discovery – 1 semester hour
            - BME 692: Fall – Design – 1 semester hour
            - BME 693: Spring – Development – 1 semester hour

B. Course Requirements

The 12-contiguous month program provides students a unique environment to focus on either Track I, product innovation or on Track II, process innovation. In reference to Figure 1 above, the Tracks may be briefly described as follows.

IA – Discovery: emphasizes the identification of needs and innovative commercially viable product solutions

IB – Nomination: emphasizes validation of needs and commercial potential to address these by products/inventions "nominated" or proposed by others
IIA – Manufacturing: emphasizes the observation of manufacturing processes and the development of alternative value streams leading to commercially beneficial improvements
IIB – Clinical: emphasizes observation of clinical processes including healthcare delivery and administrative procedures and the creation of value stream improvements in quality as defined by the Institute of Medicine: efficient, effective, equitable, timely, safety, and patient centeredness

Course requirements are identified in Table 2 below, on a Track by Track basis. Note that each Track provides for three electives totaling 9 semester hours. Program candidates, in coordination with their advisor, take these in support of their individual professional health and health care technology practice needs and objectives. Appendix 2 provides a listing, by category, of appropriate elective course options.

Table 2: Joint Department BME Revised Master's Program Curriculum

Designation	Location	Credit Hours	Focus	Title - Description	IA - Product Innovation - Discovery Credits	IB - Product Innovation - Nomination Credits	IIA - Process Innovation - Manufacturing Credits	IIB - Process Innovation - Clinical Credits
BEC 577	NC State	3	Discovery & Design	Advanced BioMfg & Biocatalysis			3	
BME 551	NC State	3	Discovery & Design	Design in BioTechnology	3	3		
BME 552	NC State	3	Discovery & Design	Proof of Concept Prototyping, Verification, and Validation	3	3		
BME 590	Either	3	Discovery & Design	Biomedical Innovation and Entrepreneurship: Needs Finding and Specification	3	3		3
IE 520	NC State	3	Discovery & Design	Healthcare Systems Performance Improvement				3

Designation	Location	Credit Hours	Focus	Title - Description	IA - Product Innovation - Discovery Credits	IB - Product Innovation - Nomination Credits	IIA - Process Innovation - Manufacturing Credits	IIB - Process Innovation - Clinical Credits
IE 521	NC State	3	Discovery & Design	Healthcare Systems Performance Improvement				3
ISE 515	NC State	3	Discovery & Design	Manufacturing Process Engineering			3	
ISE 714	NC State	3	Discovery & Design	Product Manufacturing Engineering for the Medical Device Industry			3	
Bus 533	UNC - CH	3	Finance, Accounting, & Business Tech.	Supply Chain Management			3	
Bus 854	UNC - CH	3	Finance, Accounting, & Business Tech.	Organization Design & Development				3
BUSI 504	UNC - CH	3	Finance, Accounting, & Business Tech.	Launching the Venture	3	3		
MBA 503	NC State	3	Finance, Accounting, & Business Tech.	Finance and Accounting for Managers	3	3	3	3

Designation	Location	Credit Hours	Focus	Title - Description	IA - Product Innovation - Discovery Credits	IB - Product Innovation - Nomination Credits	IIA - Process Innovation - Manufacturing Credits	IIB - Process Innovation - Clinical Credits
MBA 586	NC State	3	Management & Entrepreneurship	Legal and Marketing Dynamics in Pharmaceuticals and Bio-Technology	3	3	3	3
Grad 701	UNC - CH	1.5	Management & Entrepreneurship	Working in the clinical environment	1.5	1.5	1.5	1.5
Grad 710	UNC - CH	1.5	Management & Entrepreneurship	Professional Communications: Writing	1.5	1.5	1.5	1.5
Grad 711	UNC - CH	1.5	Management & Entrepreneurship	Professional Communications: Presenting	1.5	1.5	1.5	1.5
Grad 712	UNC - CH	1	Management & Entrepreneurship	Leadership in the work place	1	1	1	1

Designation	Location	Credit Hours	Focus	Title - Description	IA - Product Innovation - Discovery Credits	IB - Product Innovation - Nomination Credits	IIA - Process Innovation - Manufacturing Credits	IIB - Process Innovation - Clinical Credits
Grad 713	UNC - CH	1.5	Management & Entrepreneurship	Applied Project Management: Frameworks; Principles; and Technologies	1.5	1.5	1.5	1.5
BME 671	SOM/Other	1	Practicum: Special Topics - Discovery	Discovery Practicum	1	1	1	1
BME 672	Both	1	Practicum: Special Topics - Design	Design Practicum	1	1	1	1
BME 673	Both	1	Practicum: Special Topics - Development	Development Practicum	1	1	1	1
Elective* 1	Either	3	Health & Healthcare Technology	MS Advisor	3	3	3	3
Elective* 2	Either	3	Health & Healthcare Technology	MS Advisor	3	3	3	3
Elective* 3	Either	3	Health & Healthcare Technology	MS Advisor	3	3	3	3

Designation	Location	Credit Hours	Focus	Title - Description	IA - Product Innovation - Discovery Credits	IB - Product Innovation - Nomination Credits	IIA - Process Innovation - Manufacturing Credits	IIB - Process Innovation - Clinical Credits
				Total Semester Hours	37	37	37	37
				No. of Courses	17	17	17	17

*See Appendix 2 for a listing of electives to be selected by the candidate in consultation and approval of their advisor.

- **Approval/Signatures**.
  See required Signature Page included as Appendix 3 of this proposal.

- **Graduate School/Campus/UNC-GA Approval**: Once received in the Graduate School, the action will be processed as needed. Generally, items only requiring on campus approval (changes in courses, credit hours, etc.) will be handled as "Operational Items" on the Administrative Board agenda and, once approved, will be implemented as outlined above (see note under logistics).

  This proposal is for "Operational Items."

- **Transcript Notation**:
  - Current MS Research with Thesis students – transcripts will note one of the following emphasis areas: (1) imaging, (2) micro-devices, (3) pharmaco-engineering, (4) rehabilitation, (5) regenerative medicine
  - PhD candidates unable to complete their degree will be provided an MS, as appropriate, for their completed work during their last semester in the PhD Program. Their transcript will indicate specialization in one of five areas as identified by the Joint Department (http://bme.sites.unc.edu/research/): (1) imaging, (2) micro-devices, (3) pharmaco-engineering, (4) rehabilitation, (5) regenerative medicine.
  - MS non-thesis, non-research (i.e. requested changed curriculum) – transcripts will note: MS-TraIn - translation innovation and entrepreneurship

APPENDIX 1

Examples of Course Options

Joint Department of BME

Current MS Degree

Approved Statistics Course List S1

Biostatistics	BIOS 550: Basic Elements of Probability and Statistical Inference Yes BIOS 600: Principles of Statistical Inference
Education	EDUC 684: Statistical Analysis of Educational Data I EDUC 784: Statistical Analysis of Educational Data II EDUC 884: Statistical Analysis of Educational Data III
Epidemiology	EPID 715: Theory and Quantitative Methods In Epidemiology
	EPID 718: Epidemiologic Analysis of Binary Data EPID 722: Epidemiologic Analysis of Time-To-Event Data Yes EPID 733: Clinical Trials in Epidemiology Yes
Sociology	SOCI 711: Analysis of Categorical Data
Statistics	ST 515: Experimental Statistics for Engineers I ST 511: Experimental Statistics for Biological Sciences I
	Other: With Approval of DGP

Approved Math/Applied Math Courses List M1

Biomedical Engineering	BMME 515: Biomathematical Modeling
	BMME 530: Digital Signal Processing I**
	BMME 775: Image Processing and Analysis
	BMME 730: Digital Signal Processing II
	BMME 860: Numerical Methods for Biomedical Engineering
	BME 512: Biomedical Signal Processing**
	BME 712: Image Processing
Biomathematics	BMA 567: Modeling of Biological Systems**
	BMA 771: Biomathematics I**
Electrical-Computer Engineering	ECE 513: Digital Signal Processing
	ECE 514: Random Processes**
Mathematics	MATH 528: Mathematical Methods for the Physical Sciences
	MATH 535: Introduction to Probability
	MATH 547: Linear Algebra for Applications
	MATH 564: Mathematical Modeling
	MATH 566: Introduction to Numerical Analysis
	MATH 577: Linear Algebra
	MATH 661: Scientific Computation
	MATH 768: Mathematical Modeling I
	MA 501: Advanced Mathematics for Engineers and Scientists I
	MA 502: Advanced Mathematics for Engineers and Scientists II
	MA 520: Linear Algebra
	MA 523: Linear Transformations and Matrix Theory
	MA 531: Dynamic Systems and Multivariable Controls I
	MA 532: Ordinary Differential Equations I
	MA 537: Nonlinear Dynamics and Chaos
	MA 546: Probability and Stochastic Processes
	MA 580: Numerical Analysis I
	MA 719: Vector Space Methods in System Optimization
	MA 731: Dynamic Systems and Multivariable Controls II
	MA 732: Ordinary Differential Equations II
	MA 780: Numerical Analysis II
	MA 782: Advanced Numerical Linear Algebra
Other:	With Approval of DGP

**Courses marked with asterisks may be but can only be used to fulfill the Math OR Engineering requirement NOT both.

Approved Engineering Course List A1 – Biomedical Imaging Track

Strongly Recommended

BMME 550: BME 550: Medical Imaging: Ultrasound, MRI and Optical -BMME 560: BME 560: Medical Imaging: X-ray, CT and Nuclear

Biomedical Engineering Courses

BME 512: Biomedical Signal Processing**
BME 522: Medical Instrumentation
BMME 530: Digital Signal Processing**
BMME 561: (CHEM 541) Analytical Microscopy
BMME 565: Biomedical Instrumentation
BMME 580: Real-time Computer Applications I

BMME 581: Real-time Computer Applications II

BMME 712: BME 712: Biomedical Image Processing
BMME 714 Bioimaging Practicum
BMME 775: COMP 775: Medical Image Analysis

Computer Sciences / Computer Engineering Courses

COMP 665: Images, Graphics and Vision
COMP 766: Visual Solid Shape
COMP 776: Computer Vision in our 3D World
COMP 787: Visual Perception
ECE 514: Random Processes**
ECE 751: Detection and Estimation Theory
ECE 759: Pattern Recognition
ECE 763: Computer Vision
ECE 764: Digital Image Processing

Other: With Approval of DGP

**Courses marked with asterisks may be co-listed in but can only be used to fulfill the Math OR Engineering requirement NOT both.

Approved Engineering Course List A2 – Microsystems Engineering Track

Biomedical Engineering Courses

BMME 430: Digital Signal Processing I
BMME 450: Linear Control Theory
BMME 465: Biomedical Instrumentation I BMME
510: Biomaterials
BME 512: Biomedical Signal Processing**
BMME 515: Introduction to Systems Biology
BME 522: Medical Instrumentation BME 525: Bioelectricity
BMME 530: Digital Signal Processing**
BMME 532: Microelectrode Techniques
BMME 548: Linear Control Theory
BMME 551: BME 551: Medical Device Design
BMME 552: BME 552: Medical Device Design II
BMME 580: Microcontroller Applications I
BMME 581: Microcontroller Applications II
BME 590 001: Biomaterials
BME 590 004: Microfluidic Device Design
BME 595: Fundamentals of Bioanalytical Sensors
BME 790: Advanced Biomedical Microdevices

Chemistry Courses

CHEM 445: Electroanalytical Chemistry
CHEM 447: Bioanalytical Chemistry
CHEM 449: Microfabricated Chemical Measurement Systems
CHEM 541: Analytical Microscopy

Mechanical and Aerospace Engineering Courses

MAE 530: Finite Element Analysis I
MAE 589M: Micro and Nano Electromechanicsl Systems
MAE 589K: Macrofluidics, Microfluidics and Nanofluidics

Chemical Engineering Courses

CHE 596I: Colloidal and Nanoscale Engineering

Other: With Approval of DGP

**Courses marked with asterisks may be co-listed but can only be used to fulfill the Math OR Engineering requirement NOT both.

Approved Engineering Course List A3 – Rehabilitation Engineering Track

Biomedical Engineering Courses

BMME 465: Biomedical Instrumentation I
BME 467: Mechanics of Tissue and Implants Requirements
BMME 505: Biomechanics
BMME 510: Biomaterials
BME 512: Biomedical Signal Processing
BMME 515: Introduction to Systems Biology
BME 522: Medical Instrumentation
BME 525: Bioelectricity
BMME 530: Digital Signal Processing
BMME 532: Microelectrode Techniques
BME 541: Biomechanics
BME 543: Cardiovascular Biomechanics
BMME 548: Linear Control Theory
BMME 550: BME 550: Medical Imaging: Ultrasound, MRI and Optical
BMME 551: BME 551: Medical Device Design
BMME 552: BME 552: Medical Device Design II
BMME 560: BME 560: Medical Imaging: X-ray, CT and Nuclear
BME (TE) 566: Polymeric Biomaterials Engineering
BMME 580: Microcontroller Applications I
BMME 581: Microcontroller Applications II
BME 590 001: Biomaterials

Mechanical and Aerospace Engineering Courses

MAE 435: Principles of Automatic Control
MAE 461: Dynamics & Controls
MAE 469: Controls Laboratory (1 Unit)
MAE 521: Linear Control and Design for Mimo Systems
MAE 522: Non Linear System Analysis and Control
MAE 524: Principles of Mechatronic Control
MAE 531: Finite Element Analysis I
MAE 534: Mechatronics Design
MAE 535: Design of Electromechanical Systems
MAE 543: Fracture Mechanics
MAE 544: Real Time Robotics

Industrial and Systems Engineering Courses

ISE 540: Human Factors in Systems Design
ISE 541: Occupational Safety Engineering
ISE 543: Musculoskeletal Mechanics
ISE 544: Occupational Biomechanics

ISE 740: Engineering Psychology of Human-Computer Interaction
ISE 743: Ergonomic Performance Assessment
ISE 744: Human Information Processing
ISE 745: Human Performance Modeling
ISE 767: Upper Extremity Biomechanics
ISE 768: Spine Biomechanics

Other: With Approval of DGP

**Courses marked with asterisks may be co-listed but can only be used to fulfill the Math OR Engineering requirement NOT both.

Recommended Electives Course List A1E – Biomedical Imaging Track

Any Course from List M1 or S1 Not Used to Meet Engineering/Math/Statistics Requirement

BME (TE) 566: Polymeric Biomaterials Engineering
BMME 589: Systems Physiology for Biomedical Engineers
BME 583/584: Tissue Engineering Fundamentals
BME 590 002: Tissue Engineering Technologies
(Special Topics)
BME 590 005: Critical Writing in BME
BMME 770: Functional Genomics Methods

Lectures in physiology systems and lab techniques covering various functional genomic methods including DNA sequencing, gene arrays, proteomics, confocal microscopy, and imaging modalities.

BMME 790: Information Processing in the CNS
BMME 890: Biotechnology
MA 523: Linear Transforms and Matrix Theory
MA 580: Numerical Analysis I
MATH 547: Linear Algebra for Applications
MATH 661: Scientific Computation
PHYS 415: Optics
PHYS 711: Electromagnetic Theory I
PHYS 771: Advanced Spectroscopic Techniques I
PY 516: Physical Optics

Other: With Approval of Academic Advisor

Recommended Electives Course List A2E – Microsystems Engineering Track

Any Course from List M1 or S1 Not Used to Meet Engineering/Math/Statistics Requirement

BME (TE) 566: Polymeric Biomaterials Engineering
BME 583/584: Tissue Engineering Fundamentals
BMME 589: Systems Physiology for Biomedical Engineers
BME 590 002: Tissue Engineering Technologies
BME 590 005: Critical Writing in BME
BMME 740: Advanced Biomaterials
BMME 770: Functional Genomics Methods
BMME 790: Information Processing in the CNS
BMME 890: Biotechnology
CSC 530: Computational Methods in Molecular Biology
GNET 711-717: (3 x 1 credit): Bioinformatics

Other: With Approval of Academic Advisor

Recommended Electives Course List A3E – Rehabilitation Engineering Track

Any Course from List M1 or S1 Not Used to Meet Engineering/Math/Statistics Requirement

BIOL 450: Introduction to Neurobiology
BME 583/584: Tissue Engineering Fundamentals
BMME 589: Systems Physiology for Biomedical Engineers
BME 590 002: Tissue Engineering Technologies
BME 590 005: Critical Writing in BME
BMME 740: Advanced Biomaterials
BMME 770: Functional Genomics Methods
BMME 790: Information Processing in the CNS
BMME 840 Rehabilitation Engineering Design
BMME 890: Biotechnology
EPID 600: Principles of Epidemiology
EPID 620: Aging and Health
EXSS 700: Applied Statistics and Research Methods in Exercise and Sports Science
EXSS 730: Management of Athletic Injuries
EXSS 732: Human Anatomy for Athletic Trainers
EXSS 735: Sports Medicine Analysis: Special Problems Related To Sports Medicine
EXSS 739: Practicum in Athletic Training
EXSS 780: Physiology of Exercise
EXSS 781: Adult Fitness/Cardiac Rehabilitation
EXSS 782: Nutritional Aspects of Exercise
EXSS 783: Assessment of Physiological Function In Exercise
EXSS 784: Advanced Topics in Exercise Physiology
EXSS 785: Seminar in Exercise Physiology
EXSS 789: Practicum in Exercise Physiology
EXSS 890: Special Topics in Exercise and Sport Science
HBHE 600: Social and Behavioral Sciences in Public Health
HBHE 661: Medical Reporting for Electronic Media
HBHE 700: Introduction to Public Health & Public Health Education
HBHE 753: Qualitative Evaluation and Research Methods
HBHE 772: Planning Health Promotion in Community, Worksite, School, and Medical Settings
HMSC 700: Scientific Basis of Human Motion
HMSC 701: Scientific Basis of Human Motion
HMSC 702: Physiology of Exercise
HMSC 710: Muscle Mechanics and Electromyographic Kinesiology
HMSC 743: Topics In Motor Control & Motor Learning: Therapeutic Implications
HMSC 780: Introduction to Outcomes Research In Health Care
HMSC 782: Infant and Family Assessment
HMSC 782L: Laboratory in Infant and Family Assessment
HMSC 790: Advanced Kinesiology and Biomechancis
HMSC 791: Analysis of Human Motion
HMSC 793: Advanced Orthopedic Assessment and Treatment

HMSC 795: Kinetic Analysis of Human Motion
HMSC 801: Seminar in Human Movement Science
HMSC 807: Advanced Clinical Practicum in Human Movement Science
HMSC 811: Basic Aspects of Aging
HMSC 881: The Neural Basis of Motor Control
HMSC 886: Understanding Research
HMSC 887: Developmental Motor Control
IHMS 850: Issues in Motor Control & Motor Learning
NUTR 600: Human Metabolism: Macronutrients
NUTR 810: Physical Activity Epidemiology and Public Health
NUTR 812: Introduction to Obesity: From Cell to Society
NUTR 814: Obesity Epidemiology
PHYI 702: Experimental Physiology of Human Health and Disease
PSY 502: Physiological Psychology
PSY 704: Learning and Motivation
PSY 757: Innovation and Technology
PSYC 701: Behavior and Its Biological Bases I
PSYC 702: Behavior and Its Biological Bases II
PSYC 703: Advanced Biological Psychology: CNS
PSYC 704: Applications of Experimental Psychology to Health Research

Other: With Approval of Academic Advisor

Appendix 2: Proposed Examples of Electives
Joint Department BME Master of Science

BME Electives – Same for Each Track

Table 1: Discovery
Other Department(s)

Table 2: Nomination
Pharmacology
Other Department(s)

Table 3: Manufacturing
Other Department(s)

Table 4: Clinical
Other Department(s)

BME Electives – Same for Each Track

Campus	Title	Prerequisite
UNC CH	505 Biomechanics (3).	Prerequisites, MATH 383, and PHYS 116 or 118.
UNC CH	510 Biomaterials (3).	Prerequisite, BIOL 101.
UNC CH	512 Biomedical Signal Processing (3).	Prerequisites, BME 311, and ST 370 or ST 371; BME or graduate standing only. (Credit is not allowed for both BME 412 and BME 512.)
NCSU	512 Biomedical Signal Processing *3.*	*Prerequisite: BME 311, and ST 370 or ST 371.*
UNC CH	515 Introduction to Systems Biology (3).	Prerequisite, MATH 383 or 528.
UNC CH	520 Fundamentals of Materials Engineering (3).	
UNC CH	522 Medical Instrumentation (3).	Students should have a background in electronics design using operational amplifiers
NCSU	522 Medical Instrumentation *3.*	
UNC CH	525 Bioelectricity (3).	Prerequisites, BME 302 or ZO 421 and a course in electrical circuits; senior or graduate standing. (Credit is not given for both BME 425 and BME 525.)
NCSU	525 Bioelectricity *3.*	Prerequisite: BME 302 or ZO 421 and a course in electrical circuits, Senior standing or Graduate standing.
UNC CH	530 Digital Signal Processing I (3).	Prerequisite, COMP 110 or 116.
NCSU	536 Digital Control Systems *3.*	Prerequisite: ECE 435 and Graduate Standing in Engineering.
NCSU	540 Nanobiotechnology Processing, Characterization, and Applications *3.*	*Prerequisite: BIO 183 and PY 212.*
NCSU	541 Biomechanics *3.*	*Prerequisite: ZO 160 or BIO 183, BME 342, ST 370.*
UNC CH	543 Cardiovascular Biomechanics (3).	Prerequisites, BME 302, MAE 308, or CE 382.
NCSU	543 Cardiovascular Biomechanics *3.*	
UNC CH	550 Medical Imaging: Ultrasonic, Optical, and Magnetic Resonance Systems (3).	Prerequisites, BME 412, ST 370 or ST 371, and PY 208.
UNC CH	550 Medical Imaging: Ultrasonic, Optical, and Magnetic Resonance Systems (3).	Prerequisites, BIOS 550 and 430, and PHYS 128.
NCSU	550 Medical Imaging: Ultrasonic, Optical, and Magnetic Resonance Systems *3.*	*Prerequisite: BME 412, ST 370 or ST 371, and PY 208.*
NCSU	551 Medical Device Design *3.*	
UNC CH	551 Medical Device Design I (3).	Prerequisite, graduate standing.
UNC CH	552 Medical Device Design II (3).	

Campus	Title	Prerequisite
NCSU	552 Medical Device Design II *3.*	
UNC CH	560 Medical Imaging: X-Ray, CT, and Nuclear Medicine Systems (3).	Prerequisites, BIOS 550, BMME 410, and PHYS 128.
UNC CH	560 Medical Imaging: X-Ray, CT, and Nuclear Medicine Systems (3).	Prerequisites, BME 311, ST 370 or ST 371, and PY 208.
UNC CH	566 Polymeric Biomaterials Engineering (3).	Prerequisites, PY 208 and (TE 200 or CH 220 or CH 221) and (MAE 206 or CE 214).
NCSU	566 Polymeric Biomaterials Engineering *3.*	*Prerequisite: PY 208 and (TE 200 or CH 220 or CH 221 or CH 225) and (MAE 206 or CE 214).*
UNC CH	576 Mathematics for Image Computing (COMP 576) (3).	
UNC CH	580 Microcontroller Applications I (3).	
UNC CH	581 Microcontroller Applications II (3).	Prerequisites, BMME 465 and 580.
UNC CH	582 Tissue Engineering Tech (2).	Prerequisite, BIT 468, crosslisted with BIT 583.
NCSU	583 Tissue Engineering Technologies *2.*	Prerequisite: BIT 466/566 or permission of instructor.
UNC CH	584 Tissue Engineering Fundamentals (3).	Prerequisite, BIO 183 and CH 221 and (MAE 301 or MSE 301 or CHE 315 or TE 303)
NCSU	584 Tissue Engineering Fundamentals *3.*	*Prerequisite: BIO 183 and (CH 221 or CH 225) and (MAE 301 or MSE 301 or CHE 315 or TE 303).*
NCSU	590- 006 Advanced Drug Delivery	
UNC CH	740 Advanced Biomaterials (MTSC 740) (3).	Prerequisite, BMME 510.
UNC CH	770 Physiology and Methods in Genomics (4).	
UNC CH	775 Image Processing and Analysis (COMP 775) (3).	Prerequisites, COMP 665, MATH 547, and STOR 435.
UNC CH	790 Graduate Systems Physiology (3).	Prerequisite, BMME 589.
UNC CH	795 Information Processing in the Central Nervous System (3).	Prerequisite, BMME 589.
UNC CH	840 Rehabilitation Engineering Design (4). .	Prerequisite, BMME 465. Permission of the instructor for students lacking the prerequisite

Table 1: Discovery - Other Department(s)

Campus	Dept	Title	Prerequisite
NCSU	Statistics	511 Experimental Statistics For Biological Sciences I *3.*	Prerequisite: ST 311 or Graduate standing.
NCSU	Statistics	515 Experimental Statistics for Engineers I *3.*	Prerequisite: ST 361 or Graduate standing.
NCSU	ED	700 - Introduction to Research Design in Education *3*	
NCSU	ED	710 - Applied Quantitative Methods in Education I *3*	ED 700, or ECI 510, or ELP 532, or ST 507
NCSU	ED	711 - Applied Quantitative Methods in Education II *3*	ED 710
NCSU	ED	712 - Survey Methods in Educational Research *3*	ED 710
NCSU	ED	730 - Introduction to Qualitative Research in Education *3*	
NCSU	ED	731 - Advanced Qualitative Research and Data Analysis in Education *3*	ELP 736, EAC 785 or ED 730.
NCSU	ED	750 - Mixed Methods Research in Education *3*	ED 711,ED 730,ST 507, ELP736 or equivalent and/or permission of the instructor.
UNC CH	Biostat	550 Basic Elements of Probability and Statistical Inference I (GNET 636) (4).	Required preparation, two semesters of calculus (such as MATH 231, 232).
UNC CH	Biostat	660 Probability and Statistical Inference I (3).	Required preparation, three semesters of calculus (such as MATH 231, 232, 233).
UNC CH	Educ	710 Statistical Analysis of Educational Data I (4).	
UNC CH	Educ	784 Statistical Analysis of Educational Data II (4).	Prerequisite, EDUC 710. Permission of the instructor for students lacking the prerequisite.
UNC CH	Educ	884 Statistical Analysis of Educational Data III (3).	Prerequisites, EDUC 710 and 784.
UNC CH	Epid	715 Theory and Quantitative Methods in Epidemiology (4).	Prerequisites, EPID 705, EPID 710 or 711. Corequisite, BIOS 545. Required preparation, competence in SAS. Permission of the instructor required for nonmajors.

Campus	Dept	Title	Prerequisite
UNC CH	Epid	718 Analytic Methods in Observational Epidemiology (3).	Prerequisites, EPID 715 and EPID 716. Required preparation, demonstrated experience with computer-based data analysis. Permission of the instructor for nonmajors.
UNC CH	Epid	722 Epidemiologic Analysis of Time-to-Event Data (4).	Prerequisite, EPID 718. Required preparation, SAS software expertise.
UNC CH	Epid	733 Clinical Trials in Epidemiology (3).	Required preparation, introductory epidemiology and biostatistics.
UNC CH	Soc	711 Analysis of Categorical Data (3).	Permission of the instructor.

Table 2: Nomination – Pharmacology

Campus	Title	Prerequisite
UNC CH	701 Introduction to Molecular Pharmacology (3).	*Permission of the instructor.*
UNC CH	702 Principles of Pharmacology and Physiology (TOXC 702) (3).	Prerequisite, CHEM 430. Permission of the instructor for students lacking the prerequisite.
UNC CH	731 Recent Advances in the Pharmacological Sciences (1).	
UNC CH	735 Discovery Biology and Pharmacogenomics (2).	
UNC CH	738 Nanomedicine (2).	*Required preparation, completion of undergraduate major in physical or biological science or permission of the instructor*

Table 2: Nomination – Other Department(s)

Campus	Dept	Title	Prerequisite
NCSU	Statistics	511 Experimental Statistics For Biological Sciences I *3.*	Prerequisite: ST 311 or Graduate standing.
NCSU	Statistics	515 Experimental Statistics for Engineers I *3.*	Prerequisite: ST 361 or Graduate standing.
UNC CH	Biostat	550 Basic Elements of Probability and Statistical Inference I (GNET 636) (4).	Required preparation, two semesters of calculus (such as MATH 231, 232).
UNC CH	Biostat	660 Probability and Statistical Inference I (3).	Required preparation, three semesters of calculus (such as MATH 231, 232, 233).
UNC CH	Educ	710 Statistical Analysis of Educational Data I (4).	
UNC CH	Educ	784 Statistical Analysis of Educational Data II (4).	Prerequisite, EDUC 710. Permission of the instructor for students lacking the prerequisite.
UNC CH	Educ	884 Statistical Analysis of Educational Data III (3).	Prerequisites, EDUC 710 and 784.
UNC CH	Epid	715 Theory and Quantitative Methods in Epidemiology (4).	Prerequisites, EPID 705, EPID 710 or 711. Corequisite, BIOS 545. Required preparation, competence in SAS. Permission of the instructor required for nonmajors.
UNC CH	Epid	718 Analytic Methods in Observational Epidemiology (3).	Prerequisites, EPID 715 and EPID 716. Required preparation, demonstrated experience with computer-based data analysis. Permission of the instructor for nonmajors.

Campus	Dept	Title	Prerequisite
UNC CH	Epid	722 Epidemiologic Analysis of Time-to-Event Data (4).	Prerequisite, EPID 718. Required preparation, SAS software expertise.
UNC CH	Epid	733 Clinical Trials in Epidemiology (3).	Required preparation, introductory epidemiology and biostatistics.
UNC CH	Soc	711 Analysis of Categorical Data (3).	Permission of the instructor.

Table 3: Manufacturing - Other Department(s)

Campus	Title	Prerequisite
NCSU	ISE 515 Manufacturing Process Engineering *3.*	
NCSU	BEC 577 Advanced Biomanufacturing and Biocatalysis *3.*	*Graduate standing in engineering or life-science graduate program.*
NCSU	BEC 575 Global Regulatory Affairs for Medical Products *3.*	BEC 575 students must have graduate standing.
NCSU	ISE 714 Product Manufacturing Engineering for the Medical Device Industry *3.*	Prerequisite: ISE 515.
UNC CH	533 Supply Chain Management (3).	Prerequisite, BUSI 403
NCSU	MBA 503 Survey of Accounting *3.*	

Table 3: Manufacturing - Other Department(s)

Campus	Title	Prerequisite
NCSU	ISE 711 Capital Investment Economic Analysis *3.*	*Prerequisites: ISE 311 and ST 371.*
NCSU	ISE 715 Manufacturing Process Engineering *3.*	
NCSU	ISE 718 Micro/Nano-Scale Fabrication and Manufacturing *3.*	Prerequisite: ISE 316 or graduate standing in the college of engineering.

Table 4: Clinical – Other Department(s)

Campus	Title	Prerequisite
NCSU	ISE 520 Healthcare Systems Performance Improvement I *3.*	*Prerequisite: ST 372, ISE 352, ISE 361, and ISE 441.*
NCSU	ISE 521 Healthcare Systems Performance Improvement II *3.*	Prerequisite: ISE 520.
UNC CH	BUSI 854 Organizational Design and Development (3).	

ABGS Reviewer Comments: Biomedical Engineering Curriculum Revision

Reviewer #1:

I was under the impression that MS degrees required a thesis and MR degrees we the non-thesis option. This proposal has an MS non-thesis option. If that is allowable by the university, then I see no other concerns with this proposal. Is it appropriate to change the current thesis-required MS to a non-thesis MS? Is this a shortcut instead of creating a non-thesis MR program?

It is just not how I understood options as when we created our program, we didn't have an MS non-thesis option (or we didn't understand that was an option).

Reviewer #2:

The program seems fine to me.

I don't understand, however, why stats courses in CED aren't as viable per the stats courses at UNC-CH. Specifically, I mean:

ED 700 - Introduction to Research Design in Education
ED 710 - Applied Quantitative Methods in Education I
ED 711 - Applied Quantitative Methods in Education II
ED 712 - Survey Methods in Educational Research
ED 730 - Introduction to Qualitative Research in Education
ED 731 - Advanced Qualitative Research and Data Analysis in Education
ED 750 - Mixed Methods Research in Education

All of these methods courses are taught regularly in the College of Education.

Reviewer #3:

This is largely fine with me. The memo was helpful in connecting this to the earlier PSM proposal that we saw. On that one, I recall some concerns about the number of courses taught by adjuncts, timing of course offerings (would additional sections be required to accommodate the students, particularly given the condensed timeline of the Masters) and the need for premium tuition to cover the cost of teaching the additional courses.

It might be helpful to include a statement that explains whether any new courses are needed and confirms whether the current timing and capacity of the courses allows for them to be taken within the constraints of a one year program.