Self-Study Report:
Master of Engineering in Particle Technology (MEPT) Program
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A. Introduction & Program History

In the summer of 2013, the Chemical and Biomolecular Engineering Department, after discussions with Dr. James Michaels, conceived the idea to develop a professional Master of Engineering program in Particle Technology. This was motivated by the knowledge that Particle Technology was employed heavily in the process industries served by the Chemical Engineering profession and yet was not covered in any depth in undergraduate Chemical Engineering curriculums. US coverage is almost non-existent, and while coverage is better in Europe, there is still not room enough in undergraduate degree programs to give it the treatment needed by industry. With that in mind, the CBE department was motivated by two challenges and opportunities.

- The intellectual and pedagogical challenge of defining for the profession what an education in Particle Technology should look like.
- The chance to create a unique offering that bridged the gap between industry needs and undergraduate Chemical Engineering education.

In late summer of 2013, Dr. Bertrum Diemer was brought onto the team which now consisted of Drs. Diemer and Michaels and Professors Norman Wagner, Eric Furst and Abraham Lenhoff (then CBE Chair), with the aim of writing and gaining approval for a proposal to develop the MEPT program. It was expected that following approval, Drs. Diemer and Michaels would create the curriculum and co-direct the program. Diemer and Michaels were employed by DuPont and Merck, at the time but were contemplating retirement. Their long careers in industry had made them well aware of the importance Particle Technology to the process industries. Professors Wagner, Furst and Lenhoff did the bulk of proposal preparation although Drs. Diemer and Michaels participated in proposal development as time permitted. The proposal was recommended for approval by the Faculty Senate by the Committee on Graduate Studies with the concurrence of the Coordinating Committee on Education in February 2014 and was unanimously approved by the Faculty Senate February 3, 2014.

An initial class of students was offered admission in late spring 2014 and the program launched in fall semester 2014 with its first cohort of graduates having degrees conferred at end of summer semester 2015.

In Fall 2015, the Department of Chemical and Biomolecular Engineering proposed adding a 4+1 BChE/MEPT program and a program leading to a 9-credit Graduate Certificate in Particle Technology Both were unanimously approved by the Faculty Senate in February 2016.

Diemer & Michaels adopted the philosophy of avoiding industry-specific training (e.g., directed at pharmaceutical manufacture) in favor of teaching a set of fundamental principles broadly applicable across all sectors of the process industries. In addition they were guided by the Chemical Engineering paradigm of fluid mechanics, chemical kinetics, thermodynamics and mathematical modeling with applications to equipment and process design. Accordingly the MEPT core curriculum consists of:

- Four fundamentals courses in particle transport (CHEG 671), particle formation & modification kinetics (CHEG 670), particle properties and characterization (CHEG 673) and the mathematics of particulate systems (CHEG 672)
- Two applications courses in design of particle processing operations (CHEG 674) and design of particle-based products (CHEG 675)

This guiding philosophy has enabled our graduates to succeed as interns and permanent employees in many disparate industries including:

- Pharmaceuticals and their suppliers (Merck, Ashland, Johnson Matthey, West, Vertex)
- Chemicals (DuPont, Chemours, Corbion, FMC, Mitsubishi)
- Equipment design (China National Machinery Import & Export, Comi Polaris)
- Dental restoratives (Dentsply Sirona)
- Coffee (Keurig)
- Sugar (CSC Sugar – Sugaright)
- Ceramics (Corning)
- Aviation fuels (US Navy)
- Functional materials (Xergy)

Some key milestones of the program are:

- Fall 2014 – first full-time students admitted, program launches and first semester of core courses are taught
- Spring 2015 – first cohort of students complete all coursework including core and elective courses and are placed in internships
- Summer 2015 – first cohort of students complete internships
- Summer 2015 – first MEPT degrees are conferred
- Fall 2015 – first part-time students admitted to program and plan developed for navigating curriculum as a part-time student in two rather than one year
- Winter 2016 – overview course (CHEG 608), which becomes core course for the graduate certificate, is taught for the first time
- Fall 2016 – 4+1 program presented to undergraduates for the first time
- Fall 2017 – first 4+1 students admitted to program
- Summer 2017 – first part-time students complete the program
- Summer 2017 – first Graduate Certificate in Particle Technology awarded
- Summer 2018 – first 4+1 students complete the program and receive MEPT degree to go with their BChE degree

To date, the MEPT graduation rate is 96%, successfully graduating 22 of 23 students. Presently, we have 9 graduate students enrolled in our programs including 4+1 and Graduate Certificate applicants.

B. Program Compatibility with University Academic Priorities

Among the milestones mapped out in UD's Path to Prominence are excellence in professional education and a global initiative that extends UD's geographic reach:

- *Enhancing the success of our students* – the MEPT program provides a vital graduate degree with specialization better preparing our graduates for successful employment in the process industries
- Building an environment of inclusive excellence – MEPT collaborators include a group of industrial engineers and scientists that are diverse in gender, race and ethnicity representing a broad range of companies from the process industries (including Chemours, Corbion, Corning, Dentsply Sirona, DuPont, Johnson Matthey, Merck, PSRI, PSE, Vertex, West, Xergy).
- *Investing in our intellectual and physical capital* – MEPT is a premier professional degree founded in response to industry demand with industry support from the International Fine Particle Research Institute (IFPRI), strong sponsors of the program through course material sources, visiting instructors and industrial internships.
- *Strengthening interdisciplinary and global programs* – Through the use of UDCapture and Canvas@UD (and other media platforms), MEPT is accessible to University of Delaware students while on campus during their undergraduate and graduate careers and to industry professionals well beyond the Mid-Atlantic region. Students have taken and are taking our courses remotely from Vermont and Minnesota and an undergraduate completed the core course for the Graduate Certificate while in Saudi Arabia. The Vermont student completed the entire MEPT program while living and working in Vermont.
- *Fostering a spirit of innovation and entrepreneurship* – No other US institutions offer graduate programs dedicated to education in Particle Technology. Several international schools have

strong particle technology research programs but only one other international institution offers a coherent graduate degree in Particle Technology.

C. Curricular Requuirements

The requirements for earning the MEPT degree include successful completion of six 3-credit core courses, two suitable 3-credit elective courses and a 6-credit capstone industrial internship. Four of the core courses are taught in fall semester and focus on fundamentals. Two of the core courses are taught in spring semester and focus of applications. The internship is typically completed during summer semester. The core curriculum is:

Fall – Fundamentals Core

- CHEG 670 – Particle Rate Processes (3 credits)
- CHEG 671 – Particle Transport in Fluids and Powders (3 credits)
- CHEG 672 – Mathematics of Particlee Systems (3 credits)
- CHEG 673 – Particle Properties & Characterization (3 credits)

Spring – Applications Core

- CHEG 674 – Particle Processing Operations (3 credits)
- CHEG 675 – Particle Product Engineering (3 credits)

Summer – Capstone Internship

- CHEG 684 – Particle Technology Internship (6 credits)

Students may choose electives from the following approved list or seek approval to take/transfer another relevant elective from UD or an external institution.

Pre-approved Electives

- CHEG 600 – Intro to Science & Engineering of Polymer Systems
- CHEG 604 – Probability & Statistics for Engineering
- CHEG 615 – Special Topics in Mixing
- CHEG 616 – Chemistry & Physics of Surfaces & Interfaces
- CHEG 617 – Colloid Science & Engineering
- CHEM 685 – Colloid Chemistry
- CIEG 670 – Physics of Cohesive Sediment
- CIEG 679 – Sediment Transport Mechanics
- MEEG 613 – Nanomaterials & Nanotechnology
- MEEG 615 – Mechanical Properties of Materials
- PHYS 624 – Intro to Condensed Matter Physics

D. Assessments & Evaluations

We have conducted two types of external evaluations of the program. We have convened an advisory board consisting of three external experts in Particle Technology representative of both small and large industrial companies, academia and non-profit NGOs, and asked them to evaluate:

- The quality of our curriculum
- The uniqueness of our offering
- The need for our offering

A full copy of their report along with biographies of board members is given in Appendix V.

The second type of external evaluation is an assessment of our product, namely our students. This is supplied by the industrial sponsors of our internships. We use a standard evaluation form and have evaluations on 19 of our 22 graduates from their internship employer. We are missing two of these evaluations from our first year, and we did not seek an evaluation of our first part-time graduate who was already employed and well-regarded by his employer. Since then, we have begun requiring even those already-employed students to be evaluated so that the database includes data on at least two part-time students by their employers. We regard the reception of our students in industry and their attractiveness to potential employers as the primary student outcome of the program.

Advisory Board Report Summary

The following are excerpts from the report from our external advisory board:

- Need –
    - Particle Technology is central to many industries such as consumer products, pharmaceuticals, oil and gas, fine chemicals, mining, glass, concrete, food, etc. Yet because this subject is seldom taught at institutions of higher education, students rarely grasp its significance, and companies struggle to recruit new graduates who appreciate it.
    - The UD MEPT program is robust and deserves to be continued and expanded.
- Quality –
    - Profs. Michaels and Diemer have sensibly avoided to anchor their courses in a single discipline, thereby preserving generality.
    - As Professors of Practice with impressive industrial experience, they have lent considerable legitimacy to their teaching and have leveraged their contacts to provide meaningful internships to their students
    - The curriculum developed by Profs. Michaels and Diemer is well-balanced and thorough and has been expanded beyond Chemical Engineering to topics that industrial practitioners should know.
- Uniqueness –
    - The courses are bolstered with mathematics and physics seldom taught elsewhere.
    - It is rare for an institution of higher education to muster experts in all relevant Particle Technology Topics. The UD MEPT program constitutes a unique niche that no other school, to our knowledge, has yet been able to fill.

Summary of Intern Evaluations

The following characteristics were evaluated on a 0-5 scale where:

5 = Excellent/Outstanding
4 = Very Good
3 = Good
2 = Satisfactory
1 = Needs Improvement
0 = Unsatisfactory

The following table summarizes results:

Category	Average	Std Dev	Count
Quality of Work	4.47	0.82	19
Use of Time	4.68	0.48	19
Subject Competence	4.21	1.08	19
Judgement Skills	4.29	0.93	19
Interpersonal Relations	4.75	0.55	18
Adaptability	4.63	0.60	19
Problem Solving	4.08	1.27	19
Dependability	4.79	0.54	19
Communications Skills	4.00	0.96	19
Average	4.43	0.55	19

The average across all categories lies at the midpoint between outstanding and very good and the strong success our students experience in finding employment supports this assessment. Of the US citizens and permanent residents seeking employment after graduation, 88% found permanent positions. International students face a more challenging hiring environment, yet 70% of our graduates for which we have data have found permanent positions, either in the US or in their home countries. Half of those found positions in the US under the OPT program.

E. Advisement Strategies

There are several dimensions to advisement for our program which differ with the type of student (full-time, part-time, 4+1). So far there have been on the order of 10 students in the program at any given time. Since the two co-directors teach 5 of the 6 core courses, we see the students frequently enough, and get to know them well enough that there has not been a need to introduce formally scheduled advisement sessions. We are having continuous conversations with the students in which any issues can be surfaced. Generally, advisement consists of:

- Full-time students: These students take and complete the program in a single year and have very little flexibility toward course selection. We provide a list of approved electives from which they can choose or schedule time with us to discuss alternatives. The other significant advisement need pertains to internships. This applies to all student types and is discussed separately.
- Part-time students: These students need to discuss how they can navigate the program while remaining employed. We have developed a recommended two-year sequence in which the four fundamentals core courses (CHEG 670, 671, 672, 673) are taken two at a time in two subsequent

fall semesters while the two electives are taken in the first spring semester and the two applied core courses (CHEG 674 & 675) are taken in the final spring semester. The students have flexibility in how they pair the fundamentals courses for the two fall semesters of this sequence although we generally suggest that CHEG 671 (Particle Transport) be taken in the first fall semester with either CHEG 672 (Mathematics of Particle Systems) or CHEG 673 (Particle Properties and Characterization), while CHEG 670 (Particle Kinetics) be taken in the second fall semester with either CHEG 672 or CHEG 673, whichever remains.

- 4+1 students: Prior to entering the program, these students meet with their undergraduate advisor and with us and establish the plan for course selection including:
    - Those courses to be taken as an undergraduate and counted toward both the BChE and MEPT degrees
    - Those courses to be taken as an undergraduate beyond the BChE degree requirements and later transferred to the MEPT degree
    - Those courses to be taken during the +1 year.

  After that, it remains to monitor adherence to the plan and hold advisement sessions as needed to remain on track.

- Internships: The program directors are responsible for assigning industrial internships to each student. We do this with the intent of matching the subject of the intern project to the interest of the student. We ask each student to apply for multiple projects, and this provides us flexibility in making a suitable match. In addition, we review their resumes, and recommend improvements. We also make a workshop on this subject available to the students through the placement office.

F. Program Changes Since Initiation

There have been no changes to admission criteria, degree requirements or subject areas since program initiation. We have added two new dimensions:

- 4+1 BChE/MEPT degree program
- 9-credit Graduate Certificate in Particle Technology program

G. Recruiting Process

Our initial assumption when we started the MEPT program was that our typical student would be a graduate from a chemical engineering department who wanted to extend their education before taking an industrial position. We also expected foreign applicants who were interested in completing the program as a path to obtaining a job in the US. (Our internship is particularly appealing for these students). We have found that the cost of the program is an impediment for students who want to continue their education (and may be carrying significant student debt), and recent immigration decisions have had an impact on foreign student applications. Thus, enrollment of these students has been lower than expected.

Our "4+1" program in chemical engineering also has been a steady source of new students, and we will continue to work with undergraduate advisors to identify new candidates. An increasing number of graduate students from other departments (materials science, mechanical engineering, soil science) is taking individual courses, and we believe that we can draw more students into the program through 4+1

programs with those departments. Doctoral students may be interested in completing our graduate certificate as well.

Interest from working engineers interested in our various offerings (MEPT degree, the Graduate Certificate, or individual classes) has been higher than we expected, and we realize they are a significant recruitment opportunity. We will increase our recruitment efforts for these students in the coming years. Reaching this diffuse group of students employed throughout the process industries is a marketing challenge for which we'd appreciate institutional support.

In addition to this, we have been approached by several universities wishing to enter into a course-sharing arrangement with us (Cornell, Heriot-Watt, Sheffield) and we believe this an opportunity to further extend our reach and grow our program.

H. Application & Enrollment History

The following table summarizes this history from data supplied by the Office of Graduate and Professional Education (OGPE):

Application Year	Applications	Offers	Matriculated	Dropped Out	Graduated	Degree Conferral	Still In Program
2014	21	14	4	0	4	3 - J15, 1 - W16	0
2015	24	17	7	0	7	1 - J15, 2 - J16, 2 - F16, 2 - S17	0
2016	13	10	6	1	4	2 - J17, 2 - J18	1
2017	21	18	10	0	7	1 - S18, 6 - J18	3
2018	7	7	3	0	0		3
Total	86	66	30	1	22		7

The table also includes program completion indicating that only 1 student of 30 has dropped out of the program. This student was a part-time student who took three courses and in discussions with the student we found that he (a) found the mathematics required for some of the courses to be challenging and (b) had already taken the courses most relevant to his professional practice.

A column in the table is included to show degree conferral dates since there are a significant number of part-time students in the program who do not finish in the standard single year outlined in our original proposal.

OGPE data on student demographics for the 30 students matriculated into the program is summarized below:

Ethnicity
Non-resident Aliens – 43% (13)
Asian – 10% (3)
Multi-Ethnic – 7% (2)
White – 40% (12)

Gender
Female – 33% (10)
Male – 67% (20)

I. Student Placement Post-Graduation

To date, 22 students have completed the MEPT program. Their post-graduation placement has been as follows:

		Industrial Employment						
Type	Number	Total	*US*	*Non-US*	PhD Program	Post-Doc	Looking	Unknown
Full-time	5	3	*3*	*0*	1	0	1	0
Part-time	4	3	*3*	*0*	1	0	0	0
4+1	1	1	*1*	*0*	0	0	0	0
Full-time/Intl	11	7	*5*	*2*	0	1	1	2
4+1/Intl	1	0	*0*	*0*	0	0	1	0
Total	22	14	*12*	*2*	2	1	3	2
		64%	*55%*	*9%*	9%	5%	14%	9%

In this table, "full-time" indicates completing the program in one year, "part-time" indicates completing the program in two or more years, usually while employed, and "4+1" indicates students in our 4+1 BChE/MEPT program. The modifier "/Intl" indicates those on student visas requiring CPT to do their internship in the US and OPT to continue to work in the US thereafter. All others are either US citizens or permanent residents with right to work in the US.

While about half the students who have finished our program have been on student visas, the trend has been downward. In our first year, all 5 students were on student visas. Since then, the percentage has continually dropped. Of the 9 students who finished in 2018, only 33% were on student visas, and currently, only 1 student of 7 in the program (14%) is on a student visa.

Of the 10 citizens/permanent residents who have completed the program:

- 7 are employed in industry (70%), 5 with their internship employer and 2 elsewhere
    - Of the 3 part-time students in this number, 2 stayed with their employer and 1 used the internship as an opportunity to change jobs
- 2 are in PhD programs in Particle Technology-related fields
- 1 is still looking for a position

Of the 12 international students:

- 7 were employed in industry after graduation (58%)
    - 4 continued with their US internship employer, 1 worked elsewhere in the US, and 2 found positions in their country of origin
- 1 already held a doctorate before entering the program and did a post-doc after finishing the MEPT degree
- 2 are still looking for employment in the US
- 2 returned to their country of origin after which we lost contact

J. Financial Support

At program inception, all students were offered a 30% tuition scholarship. In F2017, we applied for and were granted a reduced tuition rate of $1250/credit starting in F2018 (68% of the research graduate

tuition rate $1827/credit), so there are no tuition scholarships being offered currently. This is the only form of financial support students have received and it no longer exists.

Since this is a professional degree program, there are no research assistantships. Two of the 22 students to complete the program received teaching assistantships to assist Prof. Diemer in teaching the capstone design course CHEG 432. Both had been students in this class as undergraduates. One of these students was a part-time student who actually performed TA duties for this course in both S2016 and S2017. The other student was CHEG 432 TA in S2018 when he was in the +1 year of his 4+1 BChE/MEPT program.

K. Demand and Competitive Factors

The industrial demand for this program and its unique positioning to satisfy it are well summarized in Sections D (Assessments & Evaluations) and I (Program Uniqueness).

L. Program Uniqueness

In April 2017, the International Fine Particle Research Institute (IFPRI) sponsored a workshop on particle technology education. The objective of the workshop was to assess the current state of education in particle science and engineering and whether the current state of particle technology education meets these needs. The need for education in this area is clear: essentially all process engineers in the chemical, biopharma, materials, food, and personal products industries will work on projects involving processing of particles during their career, and most will deal with particles routinely. In contrast, particle technology is an "orphan" discipline that is rarely included in engineering curricula. Most students (undergraduate and graduate) graduate with little or no education about particles and particle processing; as a result most engineers are forced to learn on the job.

A more detailed review of particle technology education shows that it is largely absent from engineering curricula (chemical, mechanical, civil, and materials science). When it does appear, it is in elective courses, either broad surveys or advanced specific courses (e.g. soil mechanics, granular dynamics). In the US, it is largely absent from the undergraduate chemical engineering curriculum, and only a small number of departments offer graduate degrees with a significant component of particle technology courses. Elements of particle technology are taught in chemical engineering curricula in the UK and much of Europe, but the coverage is minimal and inconsistent. Germany appears to be the exception: all chemical engineering students must have at least on particle technology course in order to graduate.

It is because of this mismatch between what industry needs and what academia provides that we established the MEPT program in 2014. In the ensuing four years, we are aware of only one new particle technology program being introduced in the US: an M. Eng. Program at Purdue University. That program differs significantly from ours, as it is comprised of both business and technical courses, and particle technology represents less than half of the program's content. Thus, the competitive landscape of the MEPT program has not changed substantially since we first proposed to create it.

M. Interdisciplinary Relationships

There are no interdisciplinary relationships that have been institutionalized as part of the MEPT program, but courses in other academic departments are relevant to our students and a small fraction of our students take elective courses outside the Chemical and Biomolecular Engineering Department.

Furthermore, the field of Particle Technology is inherently interdisciplinary, and this contributes to its difficulty finding a home in the current academic departmental structure. This is one reason our program is unique. Particle Technology's application in the process industries makes Chemical Engineering a logical place to position our offering, but there are clearly elements of Materials Science and Mechanical Engineering that must be incorporated into the program.

We have elective selection data for 58 courses representing 29 students (22 who have completed the program and 7 currently in it). 88% of these are CHEG courses with by far the most popular pair being

- CHEG 604 – Engineering Probability & Statistics – 62% of students
- CHEG 615 – Special Topics in Mixing – 52% of students

Other CHEG courses selected by more than one student include:

- CHEG 616 – Chemistry & Physics of Surfaces – 10% of students
- CHEG 617 – Colloid Science & Engineering – 24% of students

The non-CHEG elective selections come from Chemistry, Civil Engineering, Mathematics, Mechanical Engineering and Materials Science & Engineering and represent selections by 7 of the 29 students. Two of these students took a total of three Materials Science & Engineering courses. The others selections were one each from Chemistry, Civil Engineering, Mathematics and Mechanical Engineering.

There is a natural connection between our program and Materials Science & Engineering since production and characterization of particulate materials may be a significant element in creation of new materials and their manufacture. We are beginning to see interest in our Graduate Certificate program in Particle Technology from students in Materials Science & Engineering. If MEPT is approved for permanent status, we believe there to be opportunities to collaborate with Materials Science & Engineering, either to promote the Graduate Certificate or to explore a potential 4+1 program.

N. Adequacy of Facilities

The available facilities are adequate to support student, faculty and staff needs related to the program.

O. Budgetary Requirements

There are no budgetary requirements beyond typical unit costs.

P. Appendices

I. *Original application for provisional approval*

The original application for provisional program approval is attached as a separate PDF document. There were no open hearings nor were there any concerns raised during the process of being approved for provisional status.

II. *Letters of support*

a. Department Chair
b. College Dean

Letters of support from the CBE Department Chair and the Dean of the College of Engineering are attached as separate documents

III. *External advisory board review report with board member bios*

The external MEPT Advisory Board evaluation report and the bios of the board members are attached as separate documents.