Developing a Course-based Master of Environmental Engineering Degree

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Abstract

After completing the requirements for a civil engineering Bachelor of Science (B.S.) degree, students may be looking for additional training in sub-discipline specific topics to prepare them for entering the workforce at a more specialized level than they could otherwise. Many employers are looking to hire students with that additional training. Following the ASCE *Raise the Bar* initiative to increase the minimum education standards for practicing civil engineers, requiring a Master of Environmental Engineering degree or equivalent 30 credits may be instituted by state law to attain licensure in the future. To obtain this higher level of education, students may not necessarily require the traditional thesis-based Master of Science (M.S.) degree training since they are planning to spend their careers as consulting engineers and are not considering future research-based work. Additionally, such students want to complete their education in a shorter time frame than is typically required for a traditional research-based M.S. degree. Rose-Hulman Institute of Technology is developing an environmental engineering course-based Master of Environmental Engineering program to meet these needs.

The course-based master's program being developed would allow students to develop additional skills and to provide deeper and broader exposure to environmental engineering challenges all within a one-year timeframe. The intent of this program is to enhance students' knowledge and experiences in environmental engineering to match practitioners' desires to hire students better equipped for their specific field.

As we develop a Master of Environmental Engineering program, we look to survey existing master's programs to determine what coursework is typically included in course-based as well as traditional environmental engineering master's programs. This survey provides us insight into the collection of courses expected for an environmental engineering master's degree. For additional insight, we are surveying our Board of Advisors, composed primarily of practicing civil and environmental engineers, and other practicing environmental engineers about what knowledge and skills are needed and expected of an environmental engineering master's program graduate. This work is informing the goals of the program and aiding in identifying what coursework should be included in the program. The results from our study may serve as a good reference to other institutions considering the options available for master's programs, particularly those interested in alternatives to the traditional research-based master's programs.

Introduction

When looking to obtain a higher level of education beyond a civil engineering Bachelor of Science (B.S) degree, students may desire a course-based program in a shorter time frame than a traditional thesis-based program. Rose-Hulman Institute of Technology is developing a Master of Environmental Engineering program to meet the needs of students pursuing a career in industry or consulting through a course-based, practicum-oriented program. The program will include laboratory components and industry-related collaborations to provide students with experiential learning and professional skill development.

Within civil engineering at Rose-Hulman Institute of Technology, there is precedence of a discipline-specific, one-year course-based Master of Environmental Engineering program. Such a program was recently developed and launched for structural engineering[1]. The program consists of a year of course-work and a practicum that must be completed in the summer prior to the academic year of the master's program. The summer practicum is acknowledged as a course, where students are required to submit routine deliverables that address professional and business skills through reflection on the student's work experience or discussion with a supervising engineer on his/her work experience.

Methods

As we develop a Master in Environmental Engineering program, we surveyed existing master's programs to determine what coursework is typically included in course-based as well as traditional environmental engineering master's degree programs. This survey provided insight into the collection of courses expected for an environmental engineering master's degree. For additional insight, we surveyed our board of advisors, composed primarily of practicing civil and environmental engineers, as well as other practicing environmental engineers, about what knowledge and skills are needed and expected of an environmental engineering master's program graduate. This work informed the goals of the program and aided in identifying what coursework should be included in the program. We intend the results of our study to serve as a good reference to other institutions considering the options available for master's programs, particularly those interested in alternatives to the traditional research-based master's programs.

Survey of Existing M.S. Programs

The universities selected for our survey of existing master's program were based on the U.S. News and World Report Ranking of Universities in the U.S in 2015 category of the Top 10 Best Graduate Programs in Environmental Engineering[2] (Table 1). The Top 10 Best Graduate Programs in Environmental Engineering category was chosen to gain insight from the best programs in the U.S. which are specifically ranked because of their environmental engineering graduate program.

Table 1. Universities included in the survey of existing programs[3-12] listed in order of U.S. News and World Report ranked order[2].

Best Environmental Engineering Graduate Programs	Thesis-based	Course-based
Stanford University	x	
University of California, Berkeley	x	x
University of Illinois at Urbana-Champaign	x	x
Georgia Technological University	x	x
University of Michigan - Ann Arbor		x
University of Texas at Austin	x	x
Carnegie Mellon University		x
California Technological University		x
Johns Hopkins University		x
Virginia Polytechnic Institute and State University	x	

Survey of Practicing Civil and Environmental Engineers

We surveyed our Board of Advisors and Board of Associates during our biannual Civil Engineering Board of Advisors Meeting. The Board of Advisors is composed primarily of practicing civil and environmental engineers with substantial consulting, managing, and hiring experience. These engineers are regionally located in IN, IL, MO and TN. We also sought insight from additional consulting engineers practicing in environmental engineering. These additional consultants were from IN, GA and TX. Following internal review board requirements, informed consent was obtained from each participant prior to participation in the survey. The questions that were asked of the practicing engineers are summarized in Table 2. Questions 2, 3 and 4 used a Likert scale answer format with selection options from 1-5 with 1 defined as “strongly disagree” and 5 defined as “strongly agree”.

Table 2. Survey questions for practicing civil and environmental engineers.

1	Choose 5 of the following courses that you think are important at the master's level. Air quality engineering Aquatic environmental chemistry Contaminant transport modeling Ecology Energy and the environment Environmental biological processes (Wastewater treatment processes) Environmental physicochemical processes (Water treatment processes) Environmental river mechanics Environmental sampling and statistics Experimental pilot plant design Groundwater modeling Hydrologic modeling Low-impact development and urban hydrology Microbiology Remediation engineering River modeling Solid and hazardous waste regulation and treatment Treatment process modeling What other classes/topics (if any) would you want in a Master of Environmental Engineering degree program?
2	When hiring a new environmental engineer at the master's level, I consider what specific concentration areas or sub-specializations the student has studied.
3	When making hiring decisions I prefer a student with a traditional, thesis-based M.S. over a course-based master's degree. Please explain why you prefer one over the other.
4	I would be willing to host students for a summer internship prior to the start of their master's coursework knowing that it would require employee time for interviews, training and oversight.
5	What skills (technical and nontechnical) do you expect Master of Environmental Engineering graduates to possess over those of their B.S. Civil Engineering peers?
6	Do you have any other comments or insights as we develop a course-based master's program at Rose-Hulman Institute of Technology?

Results

Survey of Existing Master's Programs

Eight of the top 10 environmental engineering graduate programs have course-based programs. Those programs that also have a thesis-based M.S. program maintain similar requirements for both the course- and thesis-based programs except that for the thesis-based programs research credit is applied to the total credit hour requirement and a thesis is expected as a deliverable. At California Institute of Technology there is no formal M.S. program and in a few other cases (University of Michigan, Carnegie Mellon, Johns Hopkins), course-based M.S. programs are the only master's offering. At these universities the Ph.D. programs are the focus of the graduate program and a M.S. thesis is not required for completion of a Ph.D. degree. The course-work requirements are simply the baseline for full acceptance into their Ph.D. programs.

The specialty areas within environmental engineering that students may pursue at each of the programs surveyed are presented in Table 3. Specialty areas listed at several universities (Carnegie Mellon, California Institute of Technology and Johns Hopkins) are broad. At universities with more specific specialty areas, one common theme in the specialties offered is that most are related to water. As shown in Table 3, over fifty percent of the topics are related to water quality (highlighted in green), quantity (highlighted in blue) or treatment design (highlighted in red). Several additional specialty areas may also pertain less directly to water quality, such as wastewater reclamation and reuse, ground water modeling and treatment, or environmental nanotechnology. In contrast, the air quality specialty is not offered at all universities. Where the air quality specialty is offered it is the only specialty directly related to air. Only in some programs at large universities are there other specialties that might comprise a smaller air quality component (e.g. hazardous and solid waste engineering).

Table 3. Specialty areas of environmental engineering master's programs[3-12]. Water quality areas are highlighted in green, water quantity areas are highlighted in blue, air quality areas are highlighted in yellow, and treatment process areas are highlighted in red.

University	Specialty areas
Stanford University	*No formalized specialty areas are specified; dependent on research area.*
University of California-Berkeley	Air quality engineering
	Environmental fluid mechanics and hydrology
	Water quality engineering
University of Illinois at Urbana-Champaign	Air quality engineering and science
	Environmental chemistry
	Environmental information technology
	Environment and water resources system analysis
	Hazardous waste and subsurface science
	Water quality microbiology
	Water quality process engineering
	Watershed science and management
Georgia Technological University	Environmental biotechnology
	Water quality and treatment
	Wastewater reclamation and reuse
	Hazardous and solid waste engineering
	Ground water modeling and treatment
	Air quality monitoring
	Pollution control and modeling
	Environmental sciences
	Industrial ecology
University of Michigan - Ann Arbor	Ecohydrology
	Sustainable energy systems
	Water quality process engineering
	Water quality and resources engineering
University of Texas at Austin	Treatment processes
	Water resources
	Fluid mechanics and ocean engineering
	Water quality management
	Air resources
	Environmental engineering science
Carnegie Mellon University	Advanced Infrastructure Systems
	Environmental Engineering, Sustainability and Science
	Mechanics Materials and Computing
California Technological University	Environmental biology
	Environmental chemistry
	Environmental physics
The Johns Hopkins University (Course, largely online)	Environmental engineering
	Environmental engineering and science
	Environmental planning and management
Virginia Technological University	Air quality engineering
	Environmental fluid dynamics and coastal engineering
	Environmental modeling and simulation
	Environmental nanotechnology
	Hazardous waste management
	Water resources engineering
	Water and wastewater process engineering

The number of credit hours required for a master's degree ranged from 24-36 for the seven programs surveyed that use similar credit hour systems, as shown in Table 4. The specific core courses required for the graduate programs surveyed are also listed in Table 4.

Table 4. Program expectations of environmental engineering master's programs [3-12]. Common environmental engineering process classes are highlighted in blue and seminars explicitly noted as required courses are highlighted in orange.

University	Credits required	Core courses	Special requirements
Stanford University	32	Environmental Engineering Seminar Movement & Fate of Organic Contaminants in Waters Environmental Organic Reaction Chemistry Physical and Chemical Processes Environmental Biotechnology Transport Phenomena Aquatic Chemistry Environmental Microbiology Air Pollution Fundamentals	At least 10 credits required of these core required courses (seminar required; 3 seminar credits can count towards degree).
University of California-Bekeley	24	Air Qualuty Engineering Environmental Fluid Mechanics Vadose Zone Hydrology Environmental Physical-Chemical Processes Environmental Biological Processes Introduction to Hydrology Water Chemistry	
University of Illinois at Urbana-Champaign	36	Environmental Engineering Principles, Physical Environmental Engineering Principles, Chemical Environmental Engineering Principles, Biological Environmental Systems I Solid and Hazardous Waste Air Quality Modeling Atmospheric Chemistry Sustainable Infrastructure Systems Sustainable Design of Energy and Water Systems Graduate Seminar	Core requirement: at least 3 classes (only one of the "processes" courses counts towards core requirement)
Georgia Technological University	30	*No explicitly required courses - students work with faculty advisor to determine course of study compliant with desired track within environmental engineering.*	
University of Michigan - Ann Arbor	30	Aquatic Chemistry Environmental Microbiology Environmental Fluid Mechanics Introductory Seminar	
University of Texas at Austin	30	*No explicitly required courses - students work with faculty advisor to determine course of study compliant with desired track within environmental engineering.*	
Carnegie Mellon University	96 (semester course = 12 credits)	Graduate Seminar *No explicitly required courses; students must stay within the credit requirements.*	
California Technological University	135 (semester course = 9 credits)	Earth's Atmosphere Earth's Oceans Earth's Biogeochemical Cycles Current Problems in Environmental Science and Engineering Seminar in Environmental Science and Engineering	
The Johns Hopkins University (largely online)	10 (each course = 1 credit)	Environmental Biotechnology Biological Processes for Water and Wastewater Treatment Subsurface Fate and Contaminant Transport Air Quality Control Technologies Hazardous Waste Engineering and Management Physical and Chemical Processes for Water and Wastewater Treatment Water and Wastewater Treatment Plant Design	Must take 4 of 7 core course options.
Virginia Technological University	30	Environmental Chemistry Environmental Fluid Mechanics Environmental Engineering Principles	Must take 2 of 3 core course options.

Looking at the collection of core required courses between the universities we surveyed, several courses stand out as common for master's degree in environmental engineering. These courses include chemical, physical and/or biological environmental processes (highlighted in blue). Many programs also require participation in a regular seminar which may or may not be for credit (highlighted in orange). It is expected that all of the programs require seminar participation though they do not explicitly publish it.

Survey of Practicing Civil and Environmental Engineers

Table 5 summarizes practitioners' (n = 18) selection of potential course offerings. We acknowledge that most of our survey respondents are regionally located in the Midwest and that their choices of expected classes and educational expectations could be biased by their location. Practitioners' five choices of the 18 potential courses were summed to determine the perceived importance of courses. Six courses rose to the top by scoring a value of 5 or more: environmental biological processes, environmental physiochemical processes, energy and the environment, low-impact development and urban hydrology, remediation engineering, air quality engineering, and groundwater modeling. Table 6 summarizes the answers to the Likert scale survey questions.

Table 5. Practitioners' selection of important course offerings for an M.S. environmental engineering degree. The most commonly selected courses are highlighted in bold font.

Potential Course Offerings	# Times Selected
Air quality engineering	**5**
Aquatic environmental chemistry	3
Contaminant transport modeling	1
Ecology	2
Energy and the environment	**8**
Environmental biological processes (Wastewater treatment processes)	**13**
Environmental physicochemical processes (Water treatment processes)	**12**
Environmental river mechanics	1
Environmental sampling and statistics	4
Experimental pilot plant design	3
Groundwater modeling	**5**
Hydrologic modeling	4
Low-impact development and urban hydrology	**7**
Microbiology	3
Remediation engineering	**6**
River modeling	0
Solid and hazardous waste regulation and treatment	3
Treatment process modeling	4

Table 6. Summary of Likert scale questions on practitioners' survey.

Survey Questions	Number	Average	SD
When making hiring decisions I prefer a student with a traditional, thesis-based M.S. over a course-based master's degree. Please explain why you prefer one over the other.	16	3.88	0.96
I would be willing to host students for a summer internship prior to the start of their master's coursework knowing that it would require employee time for interviews, training and oversight.	16	2.69	1.01
I would be willing to host students for a summer internship prior to the start of their master's coursework knowing that it would require employee time for interviews, training and oversight.	11	3.64	1.12

Practitioners' responses to the questions requiring a written response are summarized below with responses listed in the general order of frequency:

Please explain why you prefer a thesis- or course-based master's hire over the other.
No preference:

- An individual could be hired either way; it depends mostly on personality and ability.
- Can assess focus either by classwork choices or thesis.
- Don't know.

Prefer course-based:

- Broad course exposure provides greater knowledge over the specificity of a thesis.
- Course-based provides specialty exposure due to course work in specific topics.
- Need fundamental-based education, not a thesis, for consulting engineering.

Prefer thesis-based:

- Thesis forces students to develop independent thinking skills including the ability to identify and acquire any necessary resources and new skills largely on their own.
- Communication (technical writing, presentation, team management) and time management skills developed during a thesis are beneficial in the work environment.
- A thesis allows us to see and evaluate a body of work.

What skills (technical and nontechnical) do you expect Master of Environmental Engineering graduates to possess over those of their B.S. Civil Engineering peers?

- Solid understanding of basic concepts/technologies in the field with ability to design systems from problem to solution.
- Advanced fundamental knowledge of broad-based environmental engineering program; innate understanding of conceptual knowledge (doesn't need to reference).
- Enhanced communication/professional skills (technical writing, presentation, management skills).
- Specialized skill set.
- Regulatory knowledge.

Do you have any other comments or insights as we develop a course-based master's program at Rose-Hulman Institute of Technology?

- Maintain a high level of rigor/expectations.
- Focus on application vs. theory.
- To replace thesis, need to place particular emphasis on developing independent learning and critical thinking in the students.
- Would not expect program to include water resources topics because they were addressed in B.S. CE program and can be learned on the job.
- Master's program is not a make-up program for B.S. program deficiencies. Students must initially be well-grounded in base technical training upon which the master's program should build.
- Teach economic understanding of trade-offs when faced with engineering alternatives.
- Teach field portion for remediation engineering to prepare students for first years on job.
- Teach regulatory and permitting processes.

Conclusions and Discussion

Determination of a collection of courses

Based on the findings from the surveys of existing master's programs and practitioners, and faculty expertise, Table 7 describes the specialty areas and corresponding core courses we expect to offer at Rose-Hulman Institute of Technology for the Master of Environmental Engineering degree.

Table 7. Specialty areas and corresponding core courses identified for the Master of Environmental Engineering program at Rose-Hulman Institute of Technology.

Specialty area	Set of courses
Chemical Movement: Water quality in natural systems	Environmental Aquatic Chemistry Applied Contaminant Transport Modeling Groundwater Analysis
Water Movement: Hydraulics and hydrology	Applied Hydrologic Modeling Advanced Analysis in River Modeling Environmental River Mechanics
Water Treatment: Process design in water and wastewater	Unit Operations in Environmental Engineering Advanced Water Treatment Processes Advanced Wastewater Treatment Processes

At Rose-Hulman Institute of Technology our expertise lies in the water quality, quantity and treatment processes sub-disciplines of environmental engineering. Many of the existing master's programs that we surveyed focus primarily on water quality and quantity and less on air quality. Practitioners were clear that they do consider students' concentration areas when making hiring decisions. Assuming that the collection of courses that practitioners identified as important for a Master of Environmental Engineering graduate indicate the specialty areas that they desire, water topics are important and comprise the top five courses selected. Air quality engineering is identified as an important course in the top seven courses selected; however, it is unclear whether practitioners identified air quality as important in order to develop well-rounded environmental engineer graduates or if air quality engineering is of current importance in their line of work.

Based on the foci of the programs surveyed, the focus of the courses practitioners prioritized, and the fact that we are a small program with limited faculty, we are limiting the scope of our Master of Environmental Engineering program to water.

The specific areas in water in which we might focus our program could be divided in a few ways. For the large programs, most of the specialty areas devoted to water are divided between water quality and water quantity. In many cases, these specialty areas are sub-divided further. In practice, especially for thesis-based graduate work, cross-pollination can occur between these sub-specialty areas and it may not always be entirely clear which track a student is pursuing. However, it appears that there are tracks devoted to water quality and tracks devoted to water quantity. For our program, we developed a set of classes devoted to water quality designated as chemical movement and a set of classes devoted to water quantity designated as water movement, summarized in Table 7. The classes listed in Table 7 will incorporate the topics identified by practitioners as expected knowledge areas (identified by course selection). For example, groundwater modeling and remediation engineering will be components of applied contaminant transport modeling and groundwater analysis courses, and low impact development and urban hydrology will be key components in the applied hydrologic modeling course.

Additionally, courses typical across the existing programs include environmental chemical, physical and/or biological processes courses. Practitioners agreed and prioritized the environmental biological processes and environmental physiochemical processes courses in their selection of courses expected for a Master of Environmental Engineering graduate. It is clear that a third set of courses, water treatment processes, is necessary for our program. The courses comprising our water treatment processes specialty area are listed in Table 7. These three sets of specialty areas will allow us to focus on the areas of interest identified through our survey of existing programs and our survey of practitioners, and will allow us to coordinate with our faculty expertise while still providing breadth through a relatively broad collection of courses in the water area.

The courses listed in Table 7 yield 36 credit hours of coursework. Overall the program is expected to require 48 hours of coursework[13] on the quarter-based system, which if multiplied by 2/3rds, yields the equivalent of 32 hours of coursework. Thirty-two hours of the coursework is consistent with the requirements of the graduate programs surveyed with common credit hour systems. In addition to courses identified in Table 7 taught within the civil engineering department, students will take other graduate-level courses in their areas of interest, such as energy and the environment taught in the chemical engineering department or advanced math classes offered through the mathematics department. These elective courses will allow students to obtain additional training and meet the expectations of practitioners. For example, the course energy and the environment was practitioners' third most popular course selection.

Considerations for a course-based vs. thesis-based program

When practitioners' were asked whether they prefer students from a thesis- or a course-based master's program, the majority of practitioners did not have a preference citing that individuals' personalities and abilities were the overriding reasons for hires. Otherwise, practitioners' generally preferred students from a course-based program because a course-based degree typically provides broader knowledge exposure versus the specificity of a thesis. However,

practitioners also noted that students' concentration areas or sub-specializations are a substantial factor in making hiring decisions. This discrepancy suggests that perhaps practitioners would like master's students to have specialization, but not at the level required for a thesis, and not at the expense of continuing to develop some degree of depth in all of the sub-specializations within environmental engineering. This subtle degree of specialization may be a niche area for Rose-Hulman Institute of Technology. As a small institution that cannot offer multiple specialty tracks of study but can focus in depth within the water specialty areas, we can achieve our goal of enhancing students' knowledge and experiences in environmental engineering to match practitioners' desires to hire students better equipped to consult in environmental engineering.

As some practitioners point out, the preparation of a thesis allows students to develop independent-thinking, project management and communication skills beneficial for consulting engineering. However, other practitioners do not feel strongly that a thesis is required to cultivate these professional skills but that proficiency depends heavily on the individual. One option to incorporate the practice of professional skills into a course-based master's program may be to emulate the structural engineering master's program at Rose-Hulman Institute of Technology[1] where students must complete a practicum with the requirements of an internship coupled with reflective essays on their experiences. In the structural engineering practicum, students must prepare 10 essays based on interviews with engineers employed by the interning firm and address questions that include technical, business and project management aspects of consulting engineering in structural engineering. Fifty percent of the practitioners that we surveyed stated that they would be willing to host interns prior to the start of the students' master's program knowing that such a commitment would require employee time for interviews, training and oversight.

A synergistic approach to encouraging students to develop professional skills in a course-based program is to emphasize projects within the curriculum. Additionally, we plan to include a laboratory component to the courses in treatment processes and modeling. The labs in the treatment processes courses are expected to be conducted in collaboration with the local water and wastewater plants, where students will work directly with plant operations to sample and analyze current processes and/or design for improvements. In addition to providing experiences in technical communication beyond the B.S. level, emphasizing labs would simulate additional benefits of a thesis including exposure to hands-on field work and practice in identifying problems and synthesizing solutions.

The American Academy of Environmental Engineers and Scientists (AAEES) is a professional organization devoted to serving the environmental engineering profession. If designed properly, the approach of a practicum and emphasis on labs would also allow the course-based master's program to meet the technical and professional environmental engineering body of knowledge outcomes identified by AAEES[14]. For example, after 30 hours of post-baccalaureate education, the *in-depth competence* area within the *enabling knowledge and skills outcome* specifies that students be able to solve problems using specialized tools and analyze and design environmental processes. The *lifelong learning* area within the *professional outcome* specifies that students be able to identify the substance and practice for continued professional learning, and execute independent learning[14]. By designing a course-based master's program to meet both the

technical and non-technical needs of practitioners, students will have the opportunity to achieve learning in terms of knowledge and skills that will serve them well in their professional lives.

Overall Conclusions

In general, the top environmental engineering graduate programs have specialty areas that focus primarily on water, require an average of 30 credit hours, and include core courses related to environmental engineering processes. Practitioners confirmed the importance of water-focused courses and in particular the "processes" courses. Practitioners noted that a course-based program may allow for both breadth and depth. Based on these findings, the focus of Rose-Hulman Institute of Technology's Master of Environmental Engineering program will be limited to water quality, quantity, and treatment. Practitioners also stressed the importance of incorporating opportunities for students to develop professional skills including independent thinking and communication. Requiring a practicum and incorporating a laboratory-based approach will allow students to develop these additionally desired skills, which separates this program from other course-based master's programs. Taken together, such a master's program has the potential to meet the AAEES environmental engineering body of knowledge outcomes.

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