Degree Program Documentation Master's Program Pharmaceutical Bioprocess Engineering

Part A
TUM School of Life Sciences
Technical University of Munich

General information:

- Administrative responsibility: TUM School of Life Sciences
- Name of degree program: Pharmaceutical Bioprocess Engineering
- Degree: Master of Science (M.Sc.)
- Standard duration of study and credits: 4 Semester and 120 credit points (CP)
- Form of study: full time
- Admission: Aptitude assessment (EV)
- Start: Winter semester (WiSe) 2022/2023
- Language of Instruction: German
- Main Location: Weihenstephan (Freising)
- Academic administrator (program design): Prof. Dr.-Ing. Heiko Briesen
- Contact for further questions (regarding this document): Quality Management Team qm.co@ls.tum.de
- Status as of: 30.07.2024

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1 Degree Program Objectives

1.1 Purpose

For several decades, findings from biology and biochemistry have increasingly been used for industrial production processes. The potential applications are almost unlimited due to the diversity of nature's synthesis capacity. The utilization of this potential provides processes that use different organisms with low energy input and are more cost-effective, product-friendly and environmentally friendly than comparable chemical processes. Biopharmaceutical products such as hormones, enzymes, vaccines and antibodies are a particularly prominent field in this respect. Due to their complexity, such products often cannot be chemically synthesized in the traditional way, but must be produced using biotechnology. Biotechnology therefore represents a key technology of the 21st century with great growth potential and increasing economic importance. Accordingly, the demand for qualified specialists who not only understand the biological background of the processes, but also have excellent knowledge in the field of industrial implementation of biotechnological processes, process engineering and process automation is also increasing.

The aim of the Pharmaceutical Bioprocess Engineering degree program is to train interdisciplinary engineers for biopharmaceutical production and the corresponding process engineering research and development. The task of graduates is the development and quality-assured operation of biotechnological production processes. They are able to advance the scientific understanding of corresponding products and processes, as well as translate the knowledge gained into innovations. Responsible handling of the possibilities and limitations of modern biotechnological processes is also part of the profile.

1.2 Strategic Significance

For years, the School of Life Sciences (LS) has been training process engineers who can design and conceptualize biopharmaceutical production processes. The use of fermentative/biotechnological processes is a connecting element of other related Master's programs at School of Life Sciences (Food Technology, Brewing and Beverage Technology). However, the focus of those related Master's programs is on the food and beverage industry. The Master's degree program in Pharmaceutical Bioprocess Engineering is the consecutive follow-up program to the Bachelor's degree program of the same name in Pharmaceutical Bioprocess Engineering at the Technical University of Munich (TUM), which is also based at the School of Life Sciences. The Master's program builds on this and leads to the acquisition of in-depth process engineering and methodological skills. Students also have the opportunity to specialize in a specific area of Pharmaceutical Bioprocess Engineering and to learn and deepen their independent scientific work in research-oriented topics.

The Master's degree program in Pharmaceutical Bioprocess Engineering uses the School's structures and expertise in engineering and biotechnology and complements them with a biopharmaceutical focus. Process engineering is a central area of expertise at the School of Life Sciences and is represented in the Department of Life Science Engineering. The thematic networking of the individual related degree programs mentioned above also enables students to gain an insight into different sectors of the biotechnology industry and thus acquire interdisciplinary skills.

The integration of the study program bundle into the wider environment of the School of Life Sciences offers a particular advantage for the training of pharmaceutical bioprocess technicians. The Weihenstephan campus has interdisciplinary knowledge of life sciences, especially microbiology, biochemistry and molecular biotechnology. Due to this bundling of skills required for Pharmaceutical Bioprocess Engineering, graduates with up-to-date qualifications can be trained here. Synergies also arise from the existing knowledge in the field of molecular biotechnology and the cooperation with the School of Engineering.

2 Qualification Profile

Students on the Master's degree program in Pharmaceutical Bioprocess Engineering receive in-depth training in the field of methodical engineering (together with the related Master's degree programs at School of Life Sciences) and also - specifically for them - in the field of biopharmaceutical process engineering. After completing the Master's degree program, students are able to combine the specialist knowledge they have acquired from all areas and apply it in a problem-solving manner. The competencies that graduates can demonstrate after successfully completing the Master's degree are listed below.

The content of the following qualification profile corresponds to the requirements of the Qualifications Framework for German Higher Education Qualifications (Hochschulqualifikationsrahmen - HQR) and the requirements contained therein (i) knowledge and understanding, (ii) use, application and generation of knowledge, (iii) communication and cooperation and (iv) scientific self-conception/professionalism. The formal aspects according to the HQF (admission requirements, duration, degree options) are detailed in chapters 3 and 6 as well as in the corresponding subject examination and study regulations.

Knowledge and understanding

- Graduates have in-depth knowledge of biopharmaceutical processes, products and dosage forms.
- Graduates know and understand basic process engineering operations that are used in biotechnological production.
- Graduates know and understand modern concepts from the field of industrial digitalization, such as plant automation and process control.

Use, application and generation of knowledge

- Graduates are able to analyze and design individual basic process engineering operations in order to generate and/or maintain the desired properties of pharmaceutical products.
- Graduates are able to design entire process chains in Pharmaceutical Bioprocess Engineering through a combined selection of basic process engineering operations.
- Graduates are able to apply modern concepts from the field of digitalization to specific production processes.
- Graduates are able to analyze and develop biopharmaceutical products and dosage forms.
- Graduates can use the potential of scientific innovations to further develop or redesign processes in Pharmaceutical Bioprocess Engineering through knowledge transfer.

Communication and cooperation

- Graduates are familiar with the typical working methods of the subject area and the relevant technical vocabulary.
- Graduates are proficient in interdisciplinary communication and are able to work constructively and solution-oriented in a team.
- Graduates are able to prepare, present and communicate research results in a way that is appropriate for the target group.

Scientific self-image/professionalism

- Graduates are equally qualified for a job in the biopharmaceutical industry as well as for a scientific position at a university/research institution.
- Graduates are able to formulate research questions, design and work on research projects and evaluate research results, taking into account scientific findings.
- Graduates are able to select and apply suitable statistical and model-based methods to analyze and critically evaluate complex data and processes.
- Graduates are able to critically reflect on their actions in their professional environment, especially with regard to society's increasing expectations regarding the responsible use of Pharmaceutical Bioprocess Engineering.

3 Target Groups

3.1 Target Audience

The Master's degree program in Pharmaceutical Bioprocess Engineering is aimed at graduates of a **Bachelor's degree program in** engineering or natural sciences (120 CP) of at least **six semesters** at a German or foreign university or a **degree in** bioprocess technology, food technology, brewing and beverage technology or a comparable program.

The Master's degree program in Pharmaceutical Bioprocess Engineering is an advanced and in-depth engineering degree program specifically for graduates of relevant engineering and technical Bachelor's degree programs. The program builds in particular on the TUM Bachelor's degree programs in Pharmaceutical Bioprocess Engineering. Applicants from other disciplines and career changers are prepared for a successful program of study for the TUM Master's in Pharmaceutical Bioprocess Engineering through an aptitude test and individual counseling.

Applicants should deepen their knowledge in the field of bioprocess technology with a view to a future field of activity in the (bio)pharmaceutical industry, but also want to continue their interdisciplinary education beyond this. A keen interest in manufacturing processes, creative development and innovative pharmaceutical products is a prerequisite.

Future pharmaceutical bioprocess technicians should be willing to work in an interdisciplinary team in order to be able to work innovatively in a constantly changing industry and contribute responsibly to solving problems affecting society as a whole.

The degree program is currently offered mainly in German in the required subject area and is therefore more suitable for applicants with a very good knowledge of German at TUM. However, there are increasing opportunities to participate in international exchange programs, to integrate an internship abroad, an industrial or research internship or to complete electives at a foreign university. Many electives are also offered in English at TUM and the Master's thesis can be written and supervised in English.

The program currently has an average of around 12% international students.

3.2 Prerequisites

Applicants must have successfully completed a **Bachelor's degree** in Pharmaceutical Bioprocess Engineering or a similar **engineering or technical subject.** Proof of a solid basic education in the mathematical natural sciences (biology, chemistry, physics, mathematics) is required. Knowledge of basic engineering subjects such as **technical mechanics**, **fluid mechanics** and **thermodynamics** is essential for understanding the content taught in the Master's program. In addition, skills in **pharmaceutical/biotechnological fundamentals, biochemistry, microbiology and quality management and product safety** - both theoretical and practical - must be demonstrated. The curriculum of the Bachelor's degree program in Pharmaceutical Bioprocess Engineering at the School of Life Sciences serves as a basis for comparison.

The application process includes an **aptitude test in accordance with Annex 2 FPSO.**

In principle, **120 CP** from a relevant Bachelor's degree program are required, whereby **69 CP are** specified as competencies from the subject group listed in ***Table 1*** (in accordance with Annex 2 FPSO).

Table 1 Subject group - prerequisites for the Master's degree program in Pharmaceutical Bioprocess Engineering[1]

Subject group	**CP**
Chemistry (organic, inorganic and biochemistry)	10
Mathematics incl. statistics	10
Microbiology	5
Physics	5
Hygienic design and hygienic processing	5
Fluid mechanics	5
Technical mechanics	8
Thermodynamics	6
Molecular biotechnology	5
Pharmaceutical Technology	5
Quality management and product safety	5
Total	**69**

Missing competencies are additionally acquired through admission requirements. In the event of insufficient subject-specific foundations, modules amounting to a maximum of 30 CP from the specified areas of competence can be issued as an admission requirement. These must be completed within one year of starting the program.

Applicants are expected to have the ability to think abstractly, logically and system-oriented, as well as a recognizable interest in and background knowledge of issues in the fields of food technology, related fields (e.g. beverage technology) and other fields (e.g. engineering, natural sciences, etc.).

As the lectures are largely held in German, prospective students must have sufficient knowledge of German. Foreign students must submit a language certificate recognized by TUM (B2 (Goethe), DSH-2/3, B2 (DSD II), 4 (TestDaF), telc Deutsch C1 Hochschule) together with all other documents by the application deadline.

[1] *Source: FPSO*

A good knowledge of English is also required, as specialist literature is often only available in English. B2, Abitur level, is recommended. Students can compensate for any deficits in this area by taking elective courses during their studies.

3.3 Target Numbers

The School of Life Sciences is aiming for an average enrolment of 30 students in the Master's degree program in Pharmaceutical Bioprocess Engineering, primarily to offer students from the Bachelor's degree program an advanced and in-depth study option who wish to expand their professional development opportunities. In addition, the aim is to increase the number of students from other internal TUM Bachelor's degree programs in engineering and from other German and international universities.

The current graduation rate for students on the Master's degree program in Pharmaceutical Bioprocess Engineering is almost 100%.

The brands "Weihenstephan" and the Technical University of Munich contribute to the fact that the program is always in great demand at trade fairs. There is also a high level of interest in the program at study information days.

In the period from 2017 to 2021, an average of 60 students enrolled on the Bachelor's degree program each year. In the same period, the average number of students enrolled on the advanced Master's degree program was 22.

A more restrictive aptitude procedure introduced in the winter semester 2016/17 probably led to falling applicant numbers and percentage of admissions. The aptitude procedure was revised again for the winter semester 2022/23 with the aim of harmonizing the procedure for all applicants, including TUM external and international applicants, and aiming for a higher enrollment rate for TUM external applicants with prompt applicant feedback.

The following table shows the numbers of applicants, admissions and total students between 2017 and 2021.

Table 2: Development of applicant and enrolment figures 2017 - 2021 for the Master's degree program in Pharmaceutical Bioprocess Engineering

	WS 2017/18	WS 2018/19	WS 2019/20	WS 2020/21	WS 2021/22
Applications (cases)	44	56	42	48	54
thereof international	*13*	*9*	*11*	*3*	*3*
Admissions (cases)	24	42	30	30	37
Enrollments from applications (cases)	18	34	20	19	19
Share of enrollments in admissions (cases) in %	75,0	81,0	66,7	63,3	51,4
Students (cases)	101	93	86	85	64
thereof international	*11*	*13*	*11*	*11*	*n.a.*

WS = winter semester, enrolment for this degree program only takes place in the winter semester

4 Demand Analysis

The number of employees in the biotechnology sector continues to rise. Between 2016 and 2019, the number of employees in Germany increased by 15% to over 37,000. There are currently around 680 purely biotech companies in Germany[2] . More than half of these companies work in the medical and pharmaceutical sector.

More than 850,000 people are currently employed in the biotechnology sector worldwide, which generated sales of around USD 298 billion in 2020[3] . There is strong demand for expertise in biotechnological production both in the immediate vicinity of TUM (Munich and Regensburg bioclusters) and worldwide (large-scale biotechnology industry).

Graduates of Pharmaceutical Bioprocess Engineering can be deployed in a variety of ways thanks to the wide-ranging training they receive. The core tasks of graduates lie in the planning, monitoring, control and evaluation of fermentative processes and the assurance of product quality. Due to the increasing proportion of biotechnologically produced pharmaceuticals, engineering skills are increasingly required for the partial design of bioprocess plants and components and are in demand in pharmaceutical plant engineering, as the classically trained plant engineers are usually unable to adequately deal with these problems.

Another growing market in the pharmaceutical environment is correct documentation in plant qualification and validation, which students are made aware of during their training.

As the Master's degree program in Pharmaceutical Bioprocess Engineering is also research-oriented, it also opens up fields of work in research and development in industrial laboratories, at universities and public research institutions. Finally, after successfully completing the Master's degree, students have the opportunity to do a doctorate.

Future employers for pharmaceutical bioprocess technicians can therefore be plant manufacturers for the biotechnological and pharmaceutical industry as well as manufacturers of drugs, cosmetics, food supplements or other biotechnologically produced products. Companies both in Germany and abroad can be considered.

A TUM graduate survey conducted in 2020/21 underpins the positive picture of the career situation for Master's graduates of the Pharmaceutical Bioprocess Engineering degree program.

TUM graduates have very good career opportunities on the job market. Regular graduate surveys (since 2018) have shown that almost all graduates have found a suitable job after completing their Master's degree. Almost 75% of graduates find a job within the first 3 months of completing their studies.

The majority of graduates (75%) find a career in production companies in the pharmaceutical industry, in plant construction and in research and development. Graduates also find entry-level opportunities in the chemical industry.

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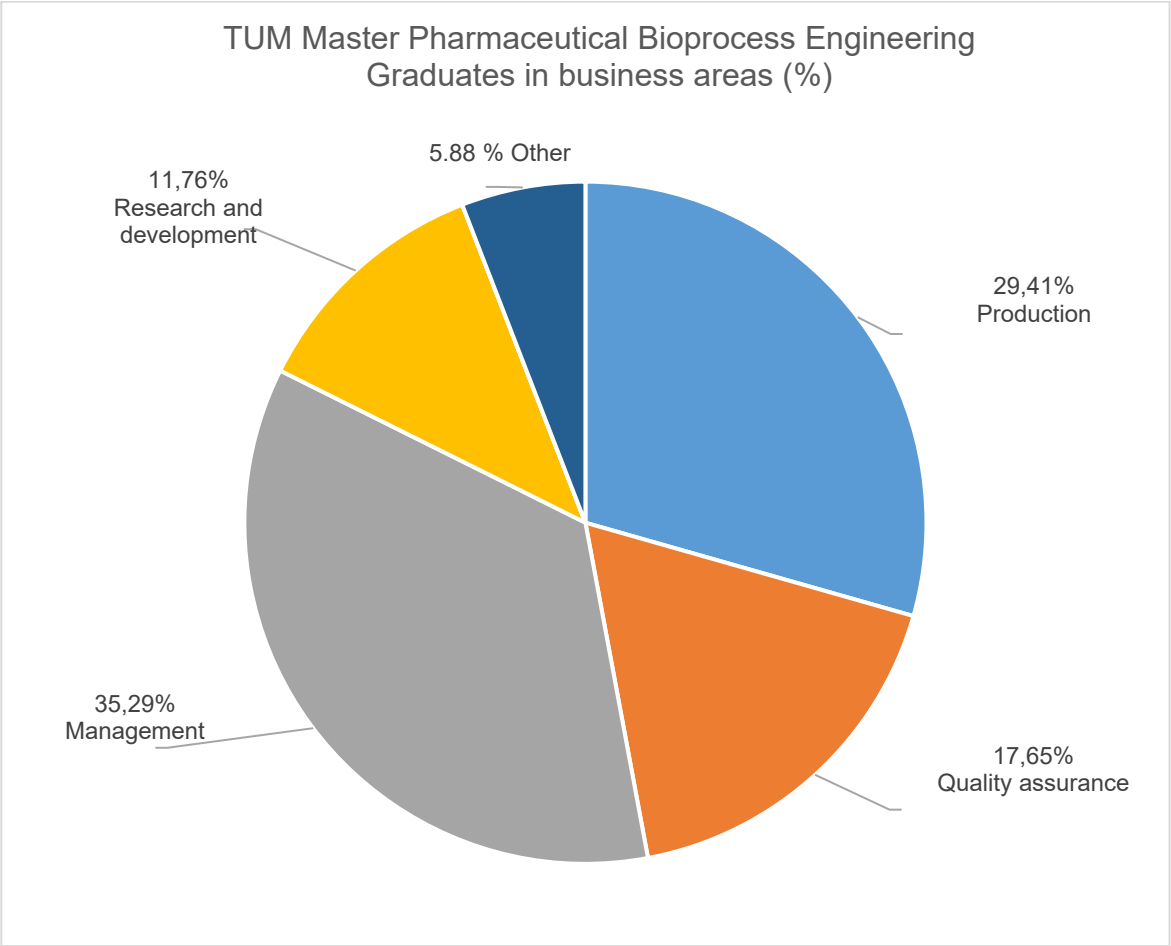
[2] Biotechnology Industry Organization Germany e.V. 2020, Statista
[3] IBISWorld

Around 29% of graduates find an interesting field of work in production and planning, around 18% in quality assurance, 35% in management/leadership and 12% in research and development (Figure 1).

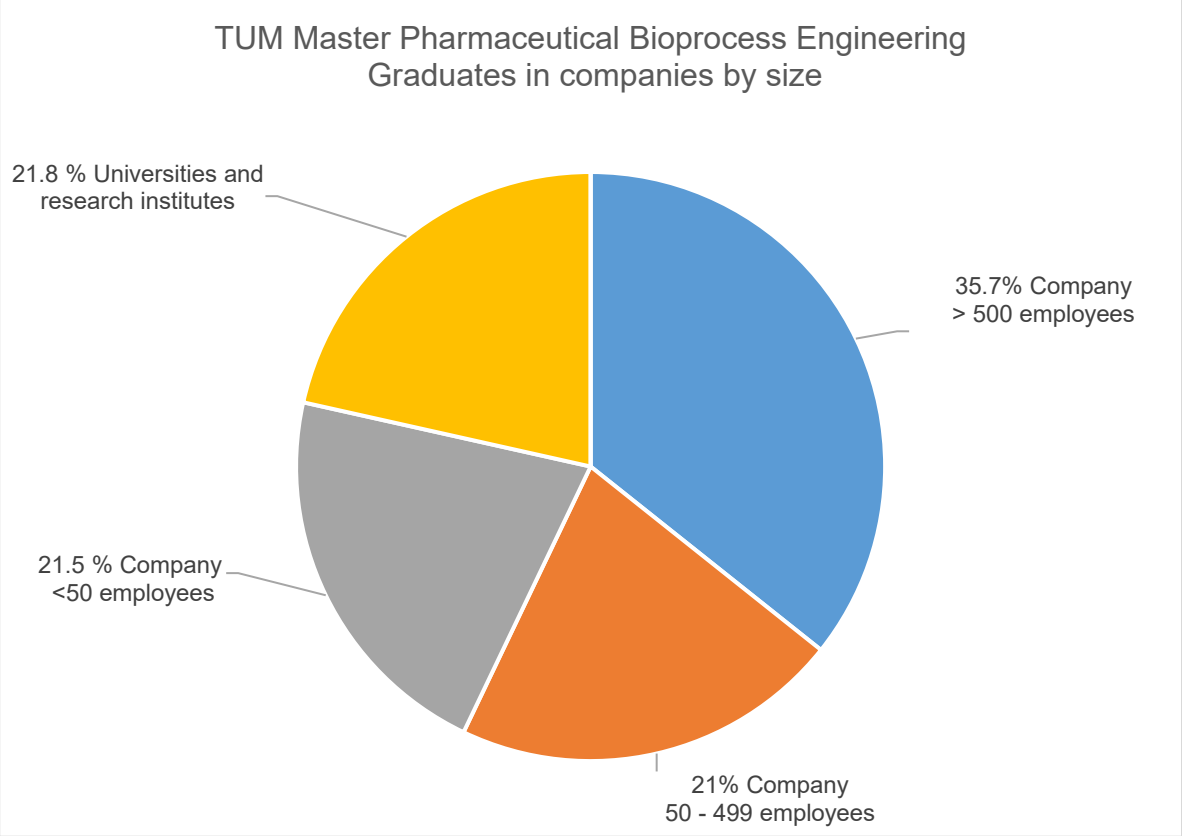
Figure 1: Entry-level fields of work for graduates of the Master's degree program in Pharmaceutical Bioprocess Engineering by degree in %



Source: Graduate survey (2018, 2020, n=16)

Surveys in the same period regarding the size of the companies in which TUM graduates found a job showed that the majority, 36% of graduates found a job in large companies and only 21% each in medium-sized and small companies (see Figure 2). In comparison, around 22% of respondents stated that they worked in research and development or teaching at a university or research institute.

Figure 2: Entry-level companies by number of employees of graduates of the Master's degree program in Pharmaceutical Bioprocess Engineering by degree (and universities) in %



Source: Graduate survey (2018, 2020, n=16)

5 Competition Analysis

5.1 External Competition Analysis

Bioprocess engineering is a form of bioprocess engineering that deals with the production of fine chemicals, basic materials and biopharmaceuticals using enzymes and prokaryotic or eukaryotic cells. As such, there are many opportunities to enter this field through a subject-specific program of study. Internationally, bioprocess engineering falls within the general and much larger field of biotechnology or specialized areas of engineering. Relevant comparative programs and providers are therefore difficult to define.

In general, many degree programs in biotechnology, or chemical and biological engineering, or specialized process engineering are offered internationally.

In Germany, students can study for a Master's degree in Bioprocess Engineering at the Hamburg University of Technology, Biotechnology at the TU Berlin, TU Braunschweig, University of Münster, Pharmaceutical Biotechnology at the University of Ulm, Biotechnology and Chemical Process Engineering at the University of Bayreuth, and Pharmaceutical and Industrial Biotechnology at the University of Halle-Wittenberg.

There are also opportunities to study for a Master's degree in Pharmaceutical Biotechnology, Industrial Biotechnology or Bioengineering at around 10 German universities of applied sciences.

The TUM Master's degree program in Pharmaceutical Bioprocess Engineering focuses on engineering and technological skills that are linked to the fields of food technology, biotechnology and process engineering.

Among German universities, TUM ranks first (no. 49 worldwide) in biotechnology and food science and technology[4] .

Studying at TUM offers students access to innovative interdisciplinary subjects from the entire TUM catalog and to a diverse network of internationally recognized TUM scientists as potential supervisors for the Master's thesis and further scientific work as part of a doctorate.

5.2 Internal Competition Analysis

There is no comparable Master's program at the TU Munich.

The following Master's degree programs at the School of Life Sciences are most closely related: ***Food Technology*** **and** ***Brewing and Beverage Technology***. Parts of the engineering specialization are taken in the Pharmaceutical Bioprocess Engineering degree program together with these two degree programs. Building on the structural and content-related relationship within process engineering and the methodological subjects of automation and control engineering as well as scientific computing, a specialization in the chosen subject area arises during the program of study. The pharmaceutical engineering and process engineering content taught in the **Master's degree program in**

[4] Shanghai Ranking, 2021 Global Ranking of Academic Subjects

Pharmaceutical Bioprocess Engineering can only be found in this program, thus enabling a clear subject-specific distinction.

In addition, there are several other degree programs at TUM that are similar to the Master's program in Pharmaceutical Bioprocess Engineering in terms of the basic principles of engineering and/or natural sciences.

The Master's degree program in ***Chemical Engineering is*** an interdisciplinary program run by the Faculties of Chemistry and Mechanical Engineering. It combines application-oriented engineering science with a specialization in chemical process engineering and biotechnology. Despite the possibility of specializing in molecular biology, there is a complete lack of pharmaceutical engineering knowledge compared to the Master's degree program in Pharmaceutical Bioprocess Engineering. However, these are in particular demand by the pharmaceutical industry, as they are of enormous importance for the development and quality assurance of biopharmaceuticals and for understanding production processes.

The interdisciplinary Master's program in ***Industrial Biotechnology****,* offered by the Munich School of Engineering at TUM, teaches the use of molecular biological methods for the biotechnological production of basic materials for the chemical industry. Although the production of chemicals and pharmaceuticals overlap in some respects, there is a lack of specific knowledge for the pharmaceutical industry.

The ***Molecular Biotechnology*** degree program at the School of Life Sciences, which tends to focus on the natural sciences, primarily deals with the structure and function of biomolecules and less with production processes and the associated technical know-how. Accordingly, there is a complete lack of application-oriented, engineering and process engineering knowledge that is necessary for understanding production processes and the associated technical requirements.

The ***Chemical Biotechnology*** program at the Straubing campus combines chemistry, molecular biology and process engineering. Industrial biotechnology, and chemical biotechnology in particular, is one of the key technologies for making industrial processes more ecological and cost-effective and for developing renewable raw materials for industrial use. One focus is the replacement of conventional industrial processes with biotechnological processes and the use of biological instead of fossil raw materials. However, here too there is a lack of knowledge and process engineering orientation specifically required for the pharmaceutical industry.

6 Program Structure

The four-semester Master's degree program in Pharmaceutical Bioprocess Engineering is designed as a full-time program (120 CP). The program builds consecutively on the Bachelor's degree program in Pharmaceutical Bioprocess Engineering offered at the School of Life Sciences. While the Bachelor's program is also characterized by a broad scientific education, and the foundations of the desired engineering orientation of the program are mainly laid there, the Master's program is increasingly aimed at deepening technical and methodological engineering skills. The structure of the program is shown in ***Figure 3***.

In the first three semesters, required and elective modules totaling 90 CP must be completed. The fourth semester is reserved for the Master's thesis (30 CP). Lectures as well as exercises, project work and internships are offered in the required and elective modules.

The program is offered in German. However, scientific project topics can optionally be worked on and supervised in English. Students can take elective modules in English.

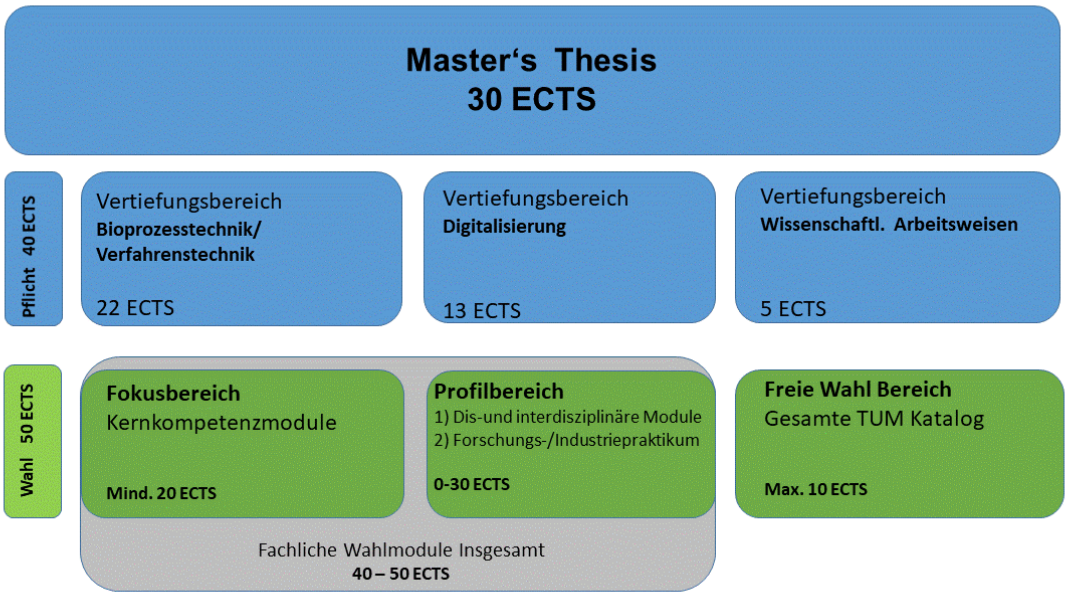
A total of 35 CP must be completed in required modules to acquire the core subject-specific competencies formulated in chapter 2 in the specializations of bioprocess engineering/technology and digitalization. Modules amounting to 35 CP are aimed at acquiring skills in the areas of scientific self-image/professionalism as well as communication and cooperation, which primarily cover the Master's thesis but also the bioprocess engineering seminar.

Students hone their own skills profile through elective modules worth 50 CP.

The elective area is divided into three areas: Focus Area, Profile Area and Free Choice Area. The desired engineering profile is ensured by selecting the modules in the focus area. The profile area is thematically broader and also allows students to acquire related skills (e.g. legal and economic skills).

As part of the profile area, students also have the choice of acquiring in-depth scientific or practical skills through an individual research internship or an industrial internship of 6 or 10 weeks for a maximum of 10 CP. Students choose their own areas of interest and are supervised internally at TUM.

Figure 3: Structure of the Master's degree program in Pharmaceutical Bioprocess Engineering



6.1 Specialization in Bioprocess Engineering and Technology (22 CP in total)

The complexity of the manufacturing process for biopharmaceuticals requires in-depth academic training in engineering science for students on the Master's program.

In the module **In-depth chapters of Pharmaceutical Bioprocess Engineering** (6 CP), current topics from science and research are addressed, deepened and supplemented with specialist knowledge. Students are made aware of currently relevant key research areas.

The process engineering program starts at the same time. The basic operations and concepts of mechanical/dispersive and thermal process engineering are taught in a **process engineering** module (9 CP), which is relevant for the entire degree program. When teaching these basic operations (e.g. filtration, distillation), the focus is on the abstract, formal description. It is shown which laws these processes follow and how these can be summarized in model equations for calculability.

In the **bioprocess engineering** module (7 CP), reactor concepts relevant to bioprocess engineering are dealt with in depth and applied to specific problems. The basic operations from mechanical and thermal process engineering, which are necessary for understanding, are assumed.

6.2 Specialization in digitalization (13 CP in total)

The demand for automation and digitalization is particularly high in the field of bioprocess technology. In order to meet the requirements of Industry 4.0 (especially digitalization), graduates need extensive methodological knowledge.

This is taught in an application-oriented manner in the **Automation and Control Engineering** module (8 CP). Not only are the theoretical skills taught, but practical exercises also ensure the application-oriented acquisition of skills.

Students acquire advanced mathematical methodological skills in the **Scientific Computing** module **(5 CP)**. Students learn methods and algorithms for data analysis and simulation of processes that go beyond the more statistical methods taught in the Bachelor's program.

6.3 Scientific working methods

The basis for independent scientific work is laid in the **bioprocess engineering seminar** (5 CP), which focuses on scientific methodology and literature research. Students should deepen their knowledge of the scientific tools they have learned in the program of their Bachelor's thesis. They learn to present and discuss results they have researched themselves and to assess their social implications.

In the final **Master's thesis** (30 CP), students must demonstrate that they can independently and competently develop, practically implement and scientifically evaluate a complex issue from the field of bioprocess engineering. By choosing a topic, students can set their preferred focus and thus further sharpen their own profile.

In seminars and final theses, students are repeatedly confronted with the responsibility of their own actions. Through reflection with supervisors and fellow students, students learn to place their actions in the context of society as a whole.

6.4 Elective options (50 CP in total)

In addition, students can deepen their skills through a wide range of elective modules worth 50 CP, depending on their inclinations and personal goals. Professional and research internships can also be taken for credit.

Graduates acquire individual, in-depth specialist skills from various flexibly selectable areas of bioprocess technology, which reflect a high degree of interdisciplinarity and allow them to develop an individual profile.

The elective area is divided into a **focus area**, a **profile area** and a **free choice area**.

The focus area consists of an elective catalog closely related to the core competencies of the degree program. Graduates must earn a minimum of 20 CP from the focus area.

The profile area also consists of a predefined list of options. It expands the range of options to include related disciplinary and interdisciplinary areas, which serve to sharpen graduates' individual profiles. Research and industrial internships can also be included in the profile area. A total of between 0 and 30 CP can be earned in the profile area, whereby a maximum of 10 CP can be credited for an internship.

In the free choice area, students can choose programs from the entire range (subject-specific or interdisciplinary) from which they expect to acquire useful skills. The selection is only limited by the fact that a maximum of 10 CP can be taken as a free choice.

Students have the optional opportunity to gain their first industrial experience as part of creditable work placements. This gives them an initial insight into their chosen industrial sector, familiarizes them with characteristic working methods and enables them to link these with the content of their studies. In this way, they are later able to act on the job market and can reflect on their own competence profile in the relevant fields of activity, continuously expand it and place the set work goals in a professional and socially meaningful context.

In optional university internships or seminars, which are often carried out in groups, students acquire the ability to solve problems in a team and acquire communication skills and team spirit. In common, frequently practiced learning groups, students motivate each other to complete examinations quickly and successfully. This enables them to recognize potential conflicts in a group, overcome them using suitable methods and thus develop a suitable solution process that leads to success. Thanks to the self-organization and individually selectable composition of the program, Master's graduates are able to assess their own weaknesses and strengths and learn to set themselves realistic work goals.

In addition to the above-mentioned elements firmly anchored in the degree program, which build and train skills such as commitment and a sense of responsibility, there is also the opportunity to gain extended experience within the framework of student activities (e.g. through activities in the student council, in the Weihenstephaner Industrierunde). Participation in TUM-wide associations and working groups can give students a broad view of interdisciplinary fields of interest.

6.5 Mobility window

A mobility window was created in the 3rd semester of the degree program. This semester is characterized by an almost complete absence of required courses. The majority of elective credits are taken here. These elective credits can also be earned by taking suitable courses at foreign universities. The required module **Bioprocess Engineering Seminar** to be completed in the 3rd semester can also be completed by taking an equivalent foreign course. However, if this is not possible, this coursework can also be completed without attending TUM, as it is a predominantly self-study module.

6.6 Exemplary Curriculum

The general course schedule over the standard period of study of four semesters is shown in ***Figure 4.***

Figure 4: General Curriculum for the Master's degree program in Pharmaceutical Bioprocess Engineering

Semester	Modules						Credits/ exams
1.	Automation and control engineering (required) 4CP	In-depth chapters of bioprocess technology (required) 6 CP	Bioprocess engineering and bioreactors (required) 3 CP	Process engineering (required) 9 CP	Elective module 1 5 CP	Elective module 2 3 CP	30/5
2.		Scientific computing (required) 5 CP	 4 CP	Elective module 3 5 CP	Elective module 4 6 CP	Elective module 5 6 CP	30/6
3. (Mobility window)	Bioprocess engineering seminar (required) 5 CP	Elective module 6 5 CP	Elective module 7 5 CP	Elective module 8 5 CP	Elective module 9 5 CP	Elective module 10 5 CP	30/6
4.	Master's Thesis 30 CP						30/1

Key: Dark blue = Final Master's thesis; Grey = required modules; Light blue = Elective modules; CP = Credits, PL = Examination

The sample Curriculum (**Figure 5**) is one of the many options for students to put together their study plan.

Figure 5: Exemplary curriculum of the Master's degree program in Pharmaceutical Bioprocess Engineering

Semester	Modules						Credits/ exams
1.	LS30006 Automation and Control Engineering (required) 4 CP	LS60013 Advanced Chapters of Bioprocess Technology (required) K 6 CP	ED180010 Bioprocess Engineering and Bioreactors (required) 3 CP	LS30001 Introduction to Micobiology (required) K 9 CP	WZ2016 Proteins: Structure, Function and Engineering K 3 CP	LS30029 Process Analysis and Digitalization (choice - focus) K 5 CP	30/5
2.		LS30007 Scientific Computing (required) K 5 CP		WZ5134 Process Simulation (Election Focus) K 5 CP	WZ5264 Scientific Computing with MATLAB (Election - Focus) M 6 CP	WZ5499 Communicating Science and Engineering (choice - profile) Portfolio 6 CP	30/6
3. Mobility window	WZ Bioprocess Engineering Seminar (required) WA 5 CP	LS30020 Research Internship (Election - Profile) B 10 CP	LS30025 Practical Apparatus Engineering in Life Sciences: A Project in the Makerspace (Choice - Profile) PA 5 CP	WZ5128 Rheology (choice - focus) K 5 CP	WZ1338 Modeling and Simulation of Disperse Systems (Option - Profile) B 5 CP		30/6
4.	WZ5907 Master's Thesis W 30 CP						30/1

Key

Dark blue = Final Master's thesis
Grey = required modules
Light blue = elective modules focus areaGreen = Profile area optional modules

SE = Seminar; CP = Credit Points; PL = Examination;
SL = Academic achievement; K = Written exam;
LL = Laboratory work; PA = Project work; PRÄ = Presentation;
W = Scientific paper

Due to the 50 CP available for electives, including a creditable internship, there are very diverse and flexible opportunities for students to specialize and take subjects from the focus, profile and the entire TUM catalog, which cannot be listed here in full.

The catalogs are constantly updated and expanded. Current information is available online on the course website and in the module handbook. Further support with specific curriculum planning, the integration of industry and research internships or a stay abroad is offered by the student advisory service.

7 Organization and Coordination

The Master program Pharmaceutical Bioprocess Engineering is offered by the TUM School of Life Sciences, the Department of Life Science Engineering at the Weihenstephan campus. Professors from all areas of the Department of Life Science Engineering are involved in teaching and supervising scientific work. In addition, the School of Engineering and Design in Garching, the Straubing Campus for Biotechnology and Sustainability and the School of Management in Munich offer and support modules in elective areas.

Academic advising is provided by the Campus Office in cooperation with the Chair of Bioprocess Engineering.

Administrative aspects of study organization are partly the responsibility of the central departments of the TUM Center for Study and Teaching (TUM CST) and partly of the TUM School of Life Sciences (see overview below):

- Student Advising: Student Advising and Information (TUM CST)
  studium@tum.de
  +49 (0)89 289 22245
  Provides information and advising for:
  prospective and current students
  (via hotline/service desk)
- Departmental Student Advising: brewing-foodtec.co@ls.tum.de
  +49 (0)8161 71 6515
- Academic Programs Office (within department/school), Infopoint, etc.:
  Campus Office Weihenstephan
  campus.office@ls.tum.de
- Study Abroad Advising/Internationalization:
  TUM-wide: TUM Global & Alumni Office
  internationalcenter@tum.de
  Departmental: Campus Office Weihenstephan
  international.co@ls.tum.de
- Gender Equality Officer: Prof. Aphrodite Kapurniotu
  akapurniotu@mytum.de
- Advising – Barrier-Free Education: TUM-wide: Service Office for Disabled and Chronically ill students and prospective students (TUM CST)
  handicap@zv.tum.de
  +49 (0)89 289 22737
- Admissions and Enrollment: Admissions and Enrollment (TUM CST)
  studium@tum.de
  +49 (0)89 289 22245
  Admissions, enrollment, Student Card,
  leave of absence, student fees payment, withdrawal

• Aptitude Assessment (EV):	TUM-wide: Admissions and Enrollment (TUM CST) Departmental: Campus Office Weihenstephan Dr. Sabine Köhler application.co@ls.tum.de +49 (0)8161 71 3336
• Semester Fees and Scholarships:	Fees and Scholarships (TUM CST) beitragsmanagement@zv.tum.de
• Examination Office:	Graduation Office and Academic Records (TUM CST) Graduation documents, notifications of examination results, preliminary degree certificates
• Departmental Examination Office:	TUM School of Life Sciences; Campus Office Weihenstephan Examination Affairs Team examination.co@ls.tum.de
• Examination Board:	Prof. Dr.-Ing. Heiko Briesen (Chairman) Ivan Babic (Secretary)
• Quality Management:	TUM-wide: Quality Management (TUM CST) https://www.tum.de/studium/tumcst/teams-cst/ Departmental: Campus Office Weihenstephan Quality Management Team qm.co@ls.tum.de Organization of QM circles, evaluation, coordination of module management
• Internship:	Advice on all questions relating to the internship and internship semester https://www.praktikantenamt-weihenstephan.de/ +49 (0)8161 / 71 3710

8 Developments in the study program

A structural standardization was achieved with regard to process engineering training. All courses included in the study program bundle (Food Technology, Brewing and Beverage Technology, Pharmaceutical Bioprocess Engineering) include a comprehensive basic education oriented towards basic process engineering operations, which is complemented by a clear subject-specific education (here: module "Bioprocess Engineering"). In terms of content, this already existed before, but was reflected differently in the various degree programs with regard to the titles of the modules.

In terms of methodological skills, structural homogeneity was achieved across the degree programs related to Pharmaceutical Bioprocess Engineering in the degree program bundle. Thus, all degree programs in the degree program bundle now jointly take the modules in the specialization area of digitalization (see section 6.2).

The transfer of certain essential content to the Master's program had become necessary due to previous changes that had already been implemented in the Bachelor's program. This was already taken into consideration when planning the previous Bachelor's conversion. Specifically, the two central modules "Process Engineering" and "Process Automation and Control Engineering" were transferred to the Master's program with an adjusted depth. Regardless of the necessity of the shift in terms of the timetable, positioning the two subject areas in the Master's is also expedient in terms of their complexity.

In order to create greater freedom of choice for students to develop their own profile despite these additional modules, the other required content has been strongly prioritized towards the core competencies. For example, the modules "Good Manufacturing Practice", "Process and Plant Engineering" and "Proteins: Structure, Function and Engineering" are no longer required. These modules, which continue to offer a particularly suitable skill set for the degree program, have instead been anchored in the focus elective area (see section 6.4. for a distinction between the various elective areas). Likewise, the obligation to carry out industrial placements was uniformly waived in all degree programs of the degree program bundle. However, industrial placements can be included as elective modules according to the students' inclinations. Other subject-specific content that was previously taught in the module "Pharmaceutical Technology 2" has been expanded with additional content and is now taught in the extended module "In-depth chapters of bioprocess technology". The required module "Physical Chemistry" was discontinued, as it was determined after analysis that the knowledge required for the overall acquisition of skills for the degree program had already been acquired in the Thermodynamics module in the Bachelor's degree program.

All of these interventions have led to students being given significantly more options to shape their own individual studies. Particularly noteworthy is the fact that the prioritization has made it possible to create a mobility window in the third semester.