

应用型本科高校围绕解决生物工程专业复杂工程问题能力培养的课程体系思考与构建

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摘 要: 准确把握专业复杂工程问题的特征与内涵是设置专业毕业要求、构建课程体系、设计教学内容的重要前提。文中通过讨论生物产业的复杂工程问题特征, 挖掘长三角地区生物产业对于本科层次人才的需求, 总结岗位典型任务和要求, 阐述了典型任务中包含的复杂工程问题的内涵。在此基础上构建了多阶段培养解决生物工程专业复杂工程问题能力的课程体系。该课程体系结合产教深度融合的医药生物技术学院、教师科研反哺教学项目建设、课程团队与一流课程建设、覆盖全员的学生专业社团建设等多种措施, 更好地支撑了解决复杂工程问题能力的培养。

关键词: 生物工程, 复杂工程问题, 典型岗位, 典型工作任务, 课程体系

Construction of the curriculum for developing the ability to solving complex engineering problems in the field of biotechnology industry

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Abstract: Accurately understanding the features and connotations of complex engineering problems is an important prerequisite for setting graduation requirements, constructing curriculum and designing teaching contents. By discussing the characteristics of complex engineering problems in the biological industry, this paper explored the demands for undergraduates in Yangtze river delta region, summarized the typical jobs and their requirements, and expounded the connotation of complex engineering problems contained in various typical tasks. On this basis, a gradual curriculum system was constructed, which

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included multiple stages of conceiving, formation and application, to cultivate the ability to solve complex engineering problems in the major of bioengineering. The curriculum coordinated the implementation of deep integration of industry and education, research feed back course construction, course team and advanced courses building up, professional associations covered all crews and students, supporting the ability training of solving complex engineering problems.

Keywords: bioengineering, complex engineering problem, typical job, typical task, curriculum

随着中国加入“华盛顿协议”，成为正式缔约成员，培养学生具备解决复杂工程问题能力就成为了我国高校拟工程认证专业的关注重点^[1]。习近平总书记在全国教育大会上指出当前教育培养的人才与现实需求还有差距，创新意识、实践能力和进取精神有待提高，特别是经济转型升级所需的创新型、应用型、复合型人才供给不足。我们要把教育同国家发展目标和需求紧密结合起来，增强人才培养的针对性、适应性，提升教育服务经济社会发展的能力^[2]。由此可见，从应对新一轮科技革命和产业变革的挑战，主动服务国家创新发展战略对工程教育提出要求的角度看，深刻理解复杂工程问题，并培养出具备解决复杂工程问题能力的毕业生，应该是我国高等教育所有工程专业的重点工作^[3]。

当前，世界范围内新一轮科技革命和产业变革加速推进。以新技术、新产业、新业态和新模式为特征的新经济呼唤“新工科”的建设，产业转型升级和旧动能转换需要“新工科”的建设^[4]。生物产业作为 21 世纪创新最为活跃、影响最为深远的新兴产业，已经成为我国战略性新兴产业的主攻方向之一，对于我国抢占新一轮科技革命和产业革命制高点，加快壮大新产业、发展新经济、培育新动能，建设“健康中国”具有重要意义^[5]。国内一些高校围绕新工科背景下生物工程专业教学与人才培养体系进行了针对性的研究。如天津大学探讨构建了新工科背景下包含基础、综合、设计、科研、实训等 5 个层次的实践教育体系^[6]；江南大学围绕人才培养方案、招生体系、课题设置、科研实践等多个方面探讨了多学科交叉的复合型研究生培养体系^[7]；华东理工大学为培养生物工

程领域新工科人才，探索了 5M (Mining-model-manipulation-measurement-manufacture) 智能生物制造新工科人才培养体系^[8]；厦门大学以系统性、综合性、模块化的方式建立了“基础-专业-综合”的实验课程体系^[9]；刘续航等对于生物工程专业高素质复合型应用人才培养方案的完善提出了在实践训练中，可以让学生在接触工作岗位中培养学生解决问题的能力，促进学生的学习与发展^[10]。

由于现代生物产业技术复杂，产业链长，覆盖面广，涉及农业、医药、化工、食品、能源、环保等众多行业，随着产业规模扩大和竞争日益加剧，产业出现了明显的区域特色和分工协作。常熟理工学院作为地处于苏州地区的地方本科院校，长期致力于为长三角区域培养适应行业发展需求的高素质应用型人才^[11-15]。但是，长三角区域对于生物工程相关专业毕业生的岗位需求有哪些？毕业生从事相关岗位需要具备怎样的基本素质和技能？相关从业者需要解决哪些特征的复杂工程问题？目前少有文献针对以上问题进行分析 and 报道。在此背景下，常熟理工学院生物工程专业以产出为导向 (Outcome-based education, OBE) 的理念，以长三角地区的产业人才需求为导向，通过对相关区域生物工程及相关专业的人才需求调研分析，凝练主要专业技术岗位的典型岗位职责和任职要求，分析岗位相关的代表性复杂工程问题，并在此基础上探讨构建围绕解决复杂工程问题能力培养的课程体系。

1 生物工程专业典型技术岗位调研与分析

1.1 人才需求调研

市场需求调研采用主流人才招聘网站检索、

行业企业走访和毕业生网络问卷调查的形式进行调研。通过网络检索(前程无忧网检索词为“江苏省+上海+生物工程或生物技术”)、毕业生网络问卷调查和代表性企业走访,收集网络检索信息 3 258 条,毕业生问卷 369 份。

1.2 人才市场典型专业技术岗位及任职要求

2018 年 3 月 15 日,通过前程无忧网检索获得 3 258 个职位。其中就业热门地点(上海+苏州+无锡+南京)职位数为 2 895 个,占比为 88%。职位对于学历要求中,本科生占比最高达到 33.2%,专科比例为 21.6%,硕士和博士占比分别为 13.4% 和 2.3%。学历要求为硕士和博士的职位主要侧重于生物医药类研发。从总体上看,上海、苏南等长三角经济发达地区生物产业经济发达,聚集了大量的生物制造、研发、生物技术服务的行业企业、科研院所,对于生物工程专业人才的需求比较旺盛。根据调研信息,合并工作内容相似的岗位,归纳出行业企业对于生物工程及相似专业招聘的 8 种主要典型专业技术岗位(不含销售岗位)及任职要求情况如表 1 所示。8 种典型岗位中有 5 种属于生物医药研发制造行业,2 种属于生物技术服务行业,1 种属于快消品制造行业。这与长三角地区集中了大量的生物医药研发制造和生物技术服务企业有关。

对表 1 中典型岗位要求进一步分析,我们认为生物工程专业从业者的典型能力包括但不限于表 2 所示。

2 生物工程复杂工程问题特征分析

生物工程是运用生物科学的理论与方法,结合现代多学科理论与工程技术,在一定的社会、经济、法律条件下,为满足人类生产、生活需求而筛选、利用、设计和改造生物体的结构和功能,以更为经济、有效、大规模地生产所需产品和提供服务的工程活动。生物工程专业建立与发展本身便是多学科交叉融合的过程,符合中国工程教育

协会认证标准中对于复杂工程问题定义的 1-7 的全部特征^[8]。其具体体现在:

(1) 需要数学、物理、化学、生物学和工程学的基础知识对工程问题进行合理的描述、分析和阐释。举例如下:

I: 生物制造涉及的化学过程的“三传一反”计算、生物反应器的设计、反应动力学过程建模、生物工艺的物料、能量衡算需要综合运用数学、物理、化学、生物等多学科知识;

II: 生物制造过程涉及的细胞代谢、细胞大规模培养、代谢途径的调控、产物的分离与精制纯化等复杂工程问题的描述、分析与解决涉及生物学、基因工程、微生物学、生物化学、发酵工程原理、生物反应器、生物分离工程等专业知识和技能的综合运用。这个特点与认证标准中关于复杂工程问题特征的第 1、2、3、4 特征点相符合。

(2) 利用现代生物工程方法生产的产品涉及的对象涵盖了医疗、能源、保健、农业、环保、化工、轻工、食品等众多领域;而在生物工程产品生产过程中需要解决的问题往往也是跨学科领域的。在社会主义新时代的生物制造和技术服务实践中,自然环境、经济利益和社会利益等方面需要包容发展以满足各方的不同利益需求,达到和谐发展的要求。这个特点与认证标准中关于复杂工程问题特征的第 5、6 和 7 特征点相符。

3 典型工作岗位的复杂工程问题分析

充分认识和深刻理解复杂工程问题的具体特征有助于设置可衡量、可评估的毕业要求,也有利于针对性地改革课程体系、教学内容、制定教学计划、组织教学形式,更有益于系统地培养学生解决复杂工程问题的能力^[3]。因此,我们结合表 1 中总结的典型岗位职责和任职要求,对相关岗位典型工作任务涉及的复杂工程问题进行了分析。分析结果如表 3 所示。

表 1 长三角区域生物工程专业人才典型技术岗位信息表

Table 1 Information of typical technical posts for bioengineering talents in Yangtze river delta

行业 Industry field	岗位 Post	占比 (%) Percentage of demand (%)	典型职责 Typical responsibilities	典型任职要求 Qualification
生物制药 Biopharm-ing	细胞培养 工程师 Cell culture engineer	26.7	1. 负责细胞培养实验室的日常维护 Responsible for the daily maintenance of the cell culture laboratory 2. 细胞培养放大及条件优化 Scale-up and optimization of cell culture conditions 3. 细胞罐的验证, 提出合理化建议 Verifying the cell tank 4. 负责客户技术问题的咨询和解答 Responsible for consulting and answering customers' technical questions	学历: 本科及以上生物工程、生物化工、制药工程、发酵工程等相关专业 Education: bachelor degree or above in biological engineering, biochemical engineering, pharmaceutical engineering, fermentation engineering or related major 综合素养*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 具备细胞培养、细胞生理代谢、工艺放大等相关专业知识和技能; 生物制药企业工作经验优先; 有单克隆抗体生产经验优先 Professional competence: have professional knowledge and skills in cell culture, cell physiology and metabolism, scale-up, etc.; working experience in biopharmaceutical industry is preferred; experience in monoclonal antibody production is preferred 学历: 专科及以上学历, 生物制药、微生物、发酵工程、生物化学工程、生物技术相关专业 Education: college degree or above, major in biopharmaceutical, microbiology, fermentation engineering, biochemical engineering, biotechnology or related fields 综合素养*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 有发酵工作经验者优先; 熟悉发酵行业的产品及技术发展动态者优先; 熟悉操作发酵罐, 熟练操作应用各种分析设备, 熟悉主要工业微生物的生理特性 Professional competence: fermentation work experience is preferred; familiar with fermentation industry product and technology development is preferred; familiar with the operation of fermenter
	发酵技术研 究员/微生物 工程师 Fermentation engineer/microbial engineer	18.7	1. 菌种复苏、传代及发酵培养 Cell resurrection, passage and culturing 2. 负责/协助完成发酵工艺放大和验证 Responsible for the amplification and validation of fermentation process 3. 负责/协助完成发酵中小试生产 Responsible for the small and medium pilot production	

(待续)

(续表 1)

行业 Industry field	岗位 Post	占比 (%) Percentage of demand (%)	典型职责 Typical responsibilities	典型任职要求 Qualification
蛋白纯化 Protein purification researcher	13.1	13.1	1. 按要求完成蛋白质的表达、纯化、检测等相关的实验室研发及分析工作 Complete laboratory research, development and analysis related to protein expression, purification and detection as required 2. 做好表达纯化实验室的日常维护, 清洁和仪器的保养工作 Responsible for the daily maintenance, cleaning and instrument maintenance of the expression purification laboratory 3. 完成表达纯化所需试剂的配制工作 Complete the preparation of reagents needed for expression and purification 4. 完善、及时、准确地做好试验记录并及时客观地向上级汇报实验进程 Completely, timely and accurate test records and report the experiment progress to the superior in a timely and objective manner	familiar with the operation and application of various analytical equipment, familiar with the physiological characteristics of main industrial microorganisms 学历: 本科及以上生物工程、生物技术、免疫学、分子生物学相关专业 Education: bachelor degree or above in bioengineering, biotechnology, immunology, molecular biology or related 综合素质*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 从事过表达及纯化工作, 精通离子交换、疏水和亲和层析理论, 并具备实践技能; 熟悉 AKTA 纯化系统及其他相关仪器设备的使用 Professional competence: engage in overexpression and purification work, proficient in ion exchange, hydrophobic and affinity chromatography theory, and have practical skills; familiar with AKTA purification system and other related equipment 学历: 本科及以上生物工程、生物技术相关专业 Education: bachelor degree or above in bioengineering, biotechnology or related 综合素质*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦
			1. 从事蛋白、抗体等生物大分子的生物化学检测相关实验研究 Engage in related experimental research on biochemical detection of biological macromolecules such as proteins and antibodies 2. 验证和优化分析方法 Validate and optimize the analytical method 3. 对蛋白、抗体质谱检测及数据处理与分析 Protein and antibody mass spectrometry detection, data processing and analysis 4. 使用英语独立撰写相关实验的 SOP 和方法开发报告 Independently composing SOP and method development reports of relevant experiments in English 5. 对项目遇到的问题和挑战, 提出可行解决方案, 确保项目在时间内、预算内完成 Proposed feasible solutions to the problems and challenges encountered in the project to ensure the completion of the project within the limits of time and budget	专业能力: 熟悉蛋白样品前处理和定性定量分析方法; 熟练掌握液相色谱、毛细管电泳、质谱等分析仪器的操作使用和日常维护; 有单克隆抗体和重组蛋白质量分析经验者优先 Professional competence: familiar with protein sample pretreatment and qualitative and quantitative analysis methods; proficient in the operation and maintenance of analytical instruments such as liquid chromatography, capillary electrophoresis and mass spectrometry experience in quality analysis of monoclonal antibodies and recombinant proteins is preferred
蛋白分析 Protein analyst	12.5	12.5		

(待续)

(续表 1)

行业 Industry field	岗位 Post	占比 (%) Percentage of demand (%)	典型职责 Typical responsibilities	典型任职要求 Qualification
生物技术服务 Biotechnology services	生物催化 Biocatalysis researcher	8.2	6. 负责实验安排及日常管理工作, 参与实验室仪器等设备、耗材的日常维护 Responsible for the arrangement and daily management of experiments, and participate in the daily maintenance of laboratory instruments and other equipment and consumables	学历: 本科及以上学历, 生物工程、生物化工、生物化学、酶工程、化学等相关专业 Education: bachelor degree or above, major in bioengineering, biochemistry, biochemistry, enzyme engineering, chemistry, etc. 综合素养*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 熟悉酶催化操作; 熟悉酶学性质研究, 理论扎实; 熟悉 HPLC、酶标仪等仪器; 具有酶催化相关项目经验者优先 Professional competence: familiar with enzyme catalysis operation; familiar with enzymatic properties, solid theory; familiar with HPLC, enzyme label instrument, etc.; experience in enzyme catalysis related projects is preferred 学历: 本科及以上学历, 分子生物学或生物工程相关专业 Education: bachelor degree or above, major in molecular biology or bioengineering 综合素养*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 有扎实的分子生物学实验技能, 包括分子克隆和基因重组; 熟悉细胞培养、细胞系和原代细胞培养, 包括细胞病毒感染等; 熟悉基因编辑, 如 CRISPR/Cas9 等; 熟练应用细胞分析鉴定技术; 熟练基本生物信息学软件技术
			1. 设计生物催化、酶催化反应, 酶筛选实验, 确认方案并组织实施 Designing biocatalysis, enzyme-catalyzed reaction and enzyme-screening experiment, confirming the plan and organized its implementation 2. 负责酶活测定, 酶学性质研究, 酶反应过程控制, 产品色谱纯度, 手性纯度的分析和评估 Responsible for enzymatic activity determination, enzymatic properties study, enzymatic reaction process control, chromatographic purity and chiral purity analysis and evaluation of products 3. 独立完成项目文献调研, 并作项目报告 Independently completed project literature research and made project report 4. 完成上级交给的其他任务 Complete other tasks assigned by superior	
生物技术服务 Biotechnology services	分子生物学 Researcher in molecular biology	10.3	1. 负责 DNA 重组工作 Responsible for DNA recombinant work 2. 负责核酸分子检测、PCR Responsible for nucleic acid molecular detection and PCR 3. 维护和保养分子生物学所用各种仪器设备 Maintain various instruments and equipment used in molecular biology 4. 参与具体实验方案设计实验准备和操作, 保持完备准确的实验记录 Participate in the design of specific experimental scheme, preparation and operation of experiments, and keep complete and accurate experimental records 5. 撰写工作和实验结果报告及技术性相关资料	学历: 本科及以上学历, 分子生物学或生物工程相关专业 Education: bachelor degree or above, major in molecular biology or bioengineering 综合素养*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 有扎实的分子生物学实验技能, 包括分子克隆和基因重组; 熟悉细胞培养、细胞系和原代细胞培养, 包括细胞病毒感染等; 熟悉基因编辑, 如 CRISPR/Cas9 等; 熟练应用细胞分析鉴定技术; 熟练基本生物信息学软件技术
			1. 负责 DNA 重组工作 Responsible for DNA recombinant work 2. 负责核酸分子检测、PCR Responsible for nucleic acid molecular detection and PCR 3. 维护和保养分子生物学所用各种仪器设备 Maintain various instruments and equipment used in molecular biology 4. 参与具体实验方案设计实验准备和操作, 保持完备准确的实验记录 Participate in the design of specific experimental scheme, preparation and operation of experiments, and keep complete and accurate experimental records 5. 撰写工作和实验结果报告及技术性相关资料	

(待续)

(续表 1)

行业 Industry field	岗位 Post	占比 (%) Percentage of demand (%)	典型职责 Typical responsibilities	典型任职要求 Qualification
微生物 Microbiology	研究员 researcher	6.4	Writing reports of work and experimental results and related technical materials	Professional competence: solid experimental skills in molecular biology, including molecular cloning and gene recombination; familiar with cell culture, cell line and primary cell culture, including cell virus infection, etc. Familiar with gene editing, such as CRISPR/Cas9, etc. proficient in cell analysis and identification techniques; skilled in basic bioinformatics software technology 学历: 本科及以上学历, 微生物学, 生物工程等相关专业
			1. 负责微生物实验室微生物培养和检测 Responsible for microbial culture and testing in microbiology laboratory 2. 负责微生物 PCR 检测及 PCR 检测项目的统筹安排 Responsible for the overall arrangement of microbial PCR detection and PCR detection items 3. 负责遵照 GLP、cGMP、GMP 等及时完成客户样本等各项检测 Responsibility for completing customer samples and other tests in accordance with GLP, cGMP, GMP, etc. 4. 负责相关实验结果的整理并出具实验报告 Responsible for sorting out relevant experimental results and issuing experimental reports 5. 负责相关设备的监控及维护 Responsible for monitoring and maintenance of related equipment	Education: bachelor degree or above, major in Microbiology, Bioengineering or related 综合素质*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 熟悉微生物及细胞培养; 精通 PCR 检测 Professional competence: familiar with microorganism and cell culture; proficient in PCR detection
食品、快消品 制造 Food, FMCG manufacturing	生物工程师 Bioengineer	4.1	1. 产品开发计划的制定和执行 Formulating and implementing product development plan 2. 已有产品维护、升级 Maintenance and upgrade of existing products 3. 技术性文章编制和撰写 (如产品审批、专利、创新成果申报等) Preparation and writing of technical articles (such as product approval, patent, innovation achievement declaration, etc.) 4. 国际化合作客户研发项目洽谈、合作及技术对接 Negotiation, cooperation and technical docking of R&D projects with international cooperation clients	学历: 本科及以上 Education: bachelor degree or above 综合素质*: ①②③④⑤⑥⑦ Comprehensive quality*: ①②③④⑤⑥⑦ 专业能力: 独立规划、承担研发项目能力; 观察和分析专业数据并准确呈现 Professional competence: ability to independently plan and undertake research and development projects; observe and analyze professional data and present them accurately

* ①交流沟通能力和能力; ②创新意识和能力; ③职业意识和知识获取能力; ④学习意识和知识获取能力; ⑤熟练的英语应用能力; ⑥熟练使用办公及专业软件; ⑦团队协作意识与能力。

* ① Communication skills; ② Innovation consciousness and ability; ③ Professional ethics and professional dedication; ④ Learning awareness and knowledge acquisition ability; ⑤ Good command of English; ⑥ Proficient in office and professional software; ⑦ Team cooperation consciousness and ability.

表 2 生物工程专业从业者典型能力项

Table 2 Typical competence items of practitioners in the Bioengineering profession

技术能力			非技术能力
Technical ability			Non-technical ability
上游 The upstream	中游 In the middle	下游 The downstream	
1. 特定工程菌株、细胞系设计、构建、筛选 Design, construction and screening of specific engineering strains and cell lines 2. 细胞株保存和培养 Cell line preservation and culture 3. 核酸分离、基因检测、分子克隆、基因编辑等服务 Nucleic acid separation, gene testing, molecular cloning, gene editing and other services 4. 相关仪器设备检定、安全使用、维护等 Verification, safe handling and maintenance of related instruments and equipment	1. 细胞大规模培养技术 Large scale cell culture technology 2. 发酵过程控制与优化 Fermentation process control and optimization 3. 针对特定生物工艺的设计与产品开发 Design and product development for specific biological processes 4. 相关仪器设备安全使用、维护 Safe handling and maintenance of relevant instruments and equipment	1. 活性小分子的分离纯化制备 Separation, purification and preparation of active small molecules 2. 功能蛋白分离纯化制备 Separation, purification and preparation of functional proteins 3. 质量监控、活性分析及方法建立 Quality control, activity analysis and method establishment 4. 相关仪器设备安全使用、维护 Safe handling and maintenance of relevant instruments and equipment	1. 法规、标准、技术、知识产权文件的理解、执行、编制、撰写 Understanding, implementation, preparation and writing of regulations, standards, technologies and intellectual property documents 2. 跨专业交流与合作 Cross-professional communication and cooperation 3. 团队协作与领导组织 Teamwork and leadership 4. 恪守职业道德，践行企业文化和工程伦理 Abide by professional ethics, practice corporate culture and engineering ethics 5. 终身学习意识与能力 Lifelong learning awareness and ability

4 本专业解决复杂工程问题能力培养的课程体系

前文对生物工程专业从业者的典型工作岗位能力、素质要求和典型工作涉及的部分代表性复杂工程问题进行了分析。我们认为培养学生解决复杂工程问题能力的关键在于使学生能够熟练运用专业原理、技术、现代化工具，在模拟或者实际工程实践中解决包含但不限于表 3 所述的相关代表性复杂工程问题。基于上述分析结果和产出导向的理念，我们依照中国工程教育认证协会标准^[16]、专业补充标准^[17]和《普通高等学校本科专业类教学质量国家标准》^[18]，设计了解决复杂工程问题能力培养的生物工程专业课程体系。

毕业生解决复杂工程问题能力的培养绝非几门课程所能够支撑，也不能仅仅依靠高年级专

业类课程学习成果，而是伴随毕业要求技术能力和非技术能力指标点的达成而形成的，本专业的通识课程、数学、自然科学和实践课程构成了解决复杂工程问题能力培养的课程体系（表 4）。同时，要加强和完善专业课程中非技术能力的教学与考核。本专业认为“工程问题”有区别于“技术问题”，解决复杂工程问题不仅关注知识综合应用和技术创新能力，更强调要分析、评价新的系统、单元（部件）或工程项目的应用对社会、健康、安全、法律以及文化等方面可能造成的影响以及问题解决方案所带来的经济成本变化，并能够理解为此应承担的责任和提供经济决策方法。因此，培养解决复杂工程问题能力更需要针对关键问题开发专业课程教学内容，改进教学方法，实施针对课程目标的多元化考核方式和评价方法加强对上述非技术能力的培养。

表 3 典型工作岗位的代表性复杂工程问题
Table 3 Typical complex engineering problems of typical jobs

岗位 Post	典型任务 Typical tasks	复杂工程问题分析 (包括但不限于) Analysis of complex engineering problems (including but not limited to)	覆盖特征* Covered characteristics
细胞培养 工程师 Cell culture engineer	针对不同细胞特性, 选用合适条件 完成满足特定要求的细胞培养 According to the characteristics of different cells, suitable conditions were selected to fulfill the specific requirements of cell culture	需要通过检索查询和阅读专业文献了解特定细胞的来源、基因特征、培养要求; 需要根据特定培养对象和目标优化选用适用的培养基; 需要在一定放大规模下利用恰当的实验设计或建立合适的细胞生长模型对培养基成分和培养条件进行优化; 根据细胞培养特征选用或设计满足需求的生物反应器; 需要能在特定的工作情境下依据相应的管理体系、标准、规范和法律规定对生产和研发过程进行管理, 并能针对特定过程编制标准操作文件 It is necessary to search and read professional literature to understand the origin, genetic characteristics and culture requirements of specific cells; it is necessary to optimize and select suitable media according to specific culture objects and objectives; it is necessary to optimize the medium composition and culture conditions by using appropriate experimental design or establishing appropriate cell growth model at a certain scale; according to the characteristics of cell culture, bioreactors were selected or designed to meet the requirements; must be able to manage production and R & D processes according to management systems, standards, codes and legal requirements in specific working situations, and be able to prepare standard operating documents for specific processes 依据客户要求, 选用合适的方法对基因进行克隆、重组、编辑、优化, 开展基因表达情况分析、细胞鉴定等定制化的研究服务, 并提供规范的分析报告; 使用通用或个性化生物信息学工具和特殊专业工具对主流数据库、研究结果进行检索和数据挖掘 According to customer requirements, select appropriate methods to clone, recombine, edit and optimize genes, carry out customized research services such as gene expression analysis and cell identification, and provide standardized analysis reports; retrieval and data mining of mainstream databases and research results using general or personalized bioinformatics tools and specialized tools	1-7
分子生物学 研究员 Researcher in molecular biology	需要与多学科人员、客户进行沟通, 了解具体需求; 在此基础上, 通过 文献和研究, 选用恰当的方法与设 备满足客户个性化服务的要求 Communicate with multidisciplinary staff and customers to understand specific needs; on this basis, through the literature and research, choose the appropriate methods and equipment to meet the customer's personalized service requirements	需要通过检索、查询和阅读专业资料了解特定菌株性质、基因特征、培养条件; 根据不同培养阶段选用和优化经济、适用的培养基成分和发酵工艺; 根据特定的发酵产物性质优化发酵工艺条件; 建立和依据合适的细胞发酵产物合成、细胞生长、底物利用等动力学模型和硬件条件进行发酵工艺优化与生物反应器放大; 针对特殊的发酵产物和过程编制技术文件 It is necessary to search, query and read professional materials to understand the nature, genetic characteristics and culture conditions of specific strains; selection and optimization of economical and suitable medium composition and fermentation process according to different culture stages; optimize	1.2,5,7
发酵技术研 究员/微生 物工程师/ 生物工程师 Fermentation technology researcher/	菌株保藏与复壮、传代, 发酵工艺 验证、发酵工艺放大和优化 Preservation and rejuvenation of strains, passage, fermentation process verification, fermentation process amplification and optimization	需要通过检索、查询和阅读专业资料了解特定菌株性质、基因特征、培养条件; 根据不同培养阶段选用和优化经济、适用的培养基成分和发酵工艺; 根据特定的发酵产物性质优化发酵工艺条件; 建立和依据合适的细胞发酵产物合成、细胞生长、底物利用等动力学模型和硬件条件进行发酵工艺优化与生物反应器放大; 针对特殊的发酵产物和过程编制技术文件 It is necessary to search, query and read professional materials to understand the nature, genetic characteristics and culture conditions of specific strains; selection and optimization of economical and suitable medium composition and fermentation process according to different culture stages; optimize	1-7

(待续)

(续表)

岗位 Post	典型任务 Typical tasks	复杂工程问题分析 (包括但不限于) Analysis of complex engineering problems (including but not limited to)	覆盖特征* Covered characteristics*
Microbial engineer/bioengineer		the fermentation conditions according to the specific fermentation product properties; the fermentation process was optimized and the bioreactor was scaled up according to the appropriate kinetics models and hardware conditions such as cell fermentation product synthesis, cell growth and substrate utilization; preparation of technical documentation for specific fermentation products and processes	
生物催化研究员 Biocatalysis researcher	根据要求设计生物催化、酶催化反应工艺, 并对过程进行监控 Design biocatalysis and enzyme catalysis reaction process according to requirements, and monitor the process	利用现代工具筛选或构建满足特定工艺要求的生物催化元件, 分析特定酶的催化特性; 设计具有特定功能酶的筛选方法; 根据特定要求分析细胞或酶催化产物性质和纯度; 结合工艺特性选用经济、安全的催化反应底物和助剂; 分析研究特定酶对所用底物的催化动力学过程, 确定影响酶发挥最大催化效益的各种因素; 建立和优化高效利用、回收酶的方法和分离产物的方法 Using modern tools to screen or construct biocatalytic elements to meet the specific process requirements and analyze the catalytic characteristics of specific enzymes; design screening methods for specific functional enzymes; analyze the properties and purity of cell or enzyme catalyzed products according to specific requirements; economic and safe catalytic reaction substrates and auxiliaries were selected according to the process characteristics; the catalytic kinetics of specific enzymes on the substrates used were analyzed and the factors affecting the maximum catalytic efficiency of the enzymes were determined; to establish and optimize the efficient utilization and recovery of enzymes and separation of products	1-7
蛋白质分离纯化/分析研究员 Protein isolation, purification/analysis researcher	酶与活性蛋白质纯化、性质分析、分离纯化工艺开发与放大 Purification of enzymes and active proteins, property analysis, separation and purification process development and amplification	针对不同细胞来源的特定活性蛋白或酶的表达进行过程优化; 通过文献检索和研究, 针对不同来源、种类蛋白或酶的特性设计纯化方法的组合策略; 选用适当、经济的纯化填料; 优化纯化工艺过程; 分析纯化过程蛋白的量和活性 Process optimization for the expression of specific active proteins or enzymes from different cell sources; through literature search and research, the combination strategies of purification methods were designed according to the characteristics of different sources and types of proteins or enzymes; choose appropriate and economical purification filler; optimize the purification process; the amount and activity of proteins during purification were analyzed	1-7
微生物研究员 Microbiology researcher	负责遵照 GLP、GMP 等及时完成客户样本等各项检测 Responsible for completing customer sample testing in time according to GLP, GMP, etc.	按照标准与要求筛查产品中的有害生物、分析环境微生物菌群以及超限事件的溯源分析; 根据所需达到的鉴定水平选择鉴定方法, 明确所采用鉴定系统的局限性及所要达到的鉴定水平 (属、种、菌株), 选用最适合要求的鉴定技术, 必要时采用多种鉴定方法确定 According to the standards and requirements, the harmful organisms in the products are screened, the environmental microflora is analyzed, and the source of the over-limit events is analyzed; the identification method should be selected according to the required identification level, the limitations of the identification system used and the identification technology should be selected, and a variety of identification methods should be adopted if necessary	1-5, 7

* 中国工程教育专业认证协会界定的 7 个复杂工程问题特征^[8]。* 7 characteristics of complex engineering problems defined by China Association for Professional Accreditation of Engineering Education^[8]。

表 4 本专业培养解决复杂工程问题能力的阶段与课程体系
Table 4 The curriculum for developing the ability to solve complex engineering problems of bioengineering

能力培养阶段		课程
Ability development stages		Curricula
孕育：掌握复杂工程问题识别、判断所需数理、工程基础、专业基础、人文素养等基础知识 Incubation period: master the basic knowledge of mathematics, engineering foundation, professional foundation, humanistic quality and so on required for the identification and judgment of complex engineering problems	课程模块 Curricula modules	
	基础人文素养 Humanities	思想道德修养、法律基础、英语读写、英语口语、入学教育、体育、军事理论、军事技能训练、心理健康教育、中国近代史纲要、毛泽东思想和中国特色社会主义社会理论体系概论、马克思主义基本原理概论、职业发展与创业教育、人文艺术与社会科学公共课程、第二课堂等 Ideological and moral cultivation and basic law education, English Reading and Writing, Oral English, Entrance Education, Physical Education, Military Theory, Military Skill Training, Psychological health education, Outline of Chinese modern history, MAO Zedong thought and theory system of socialism with Chinese characteristics, Basic principle of Marxist fundamental principles, Career development and entrepreneurship education, Arts and humanities and social science public courses, Extracurricular Activities, etc.
	数理与工程基础 Fundamentals of Mathematics, Physics and Engineering	高等数学、线性代数、概率统计与实验数据分析、大学物理、电工学、机械制图、计算机信息技术、生物信息与生物大数据挖掘等 Advanced mathematics, Linear algebra, Probability statistics and experimental data analysis, College physics, Electrotechnics, Mechanical drawing, Computer information technology, Bioinformatics and Biological Big Data Mining, etc.
	专业基础与行业认知 Professional foundation and industry knowledge	化工原理及实验、无机及分析化学、无机及分析化学实验、有机化学、有机化学实验、物理化学、生物化学、生物化学实验、微生物学、微生物学实验、分子生物学与基因工程原理、细胞生物学、生物制造与服务企业见习、生物工程专业导论、工程伦理与项目管理、生物工程专业英语等 Principles of chemical engineering and experiment, Inorganic and analytical chemistry, Inorganic and analytical chemistry, organic chemistry, Organic chemistry experiments, Physical chemistry, Biochemistry, Microbiology, Biochemistry experiment, Microbiology experiment principle, Cell biology, Molecular biology and genetic engineering, Internship in biofabrication and service enterprise, Introduction to biological engineering, Engineering ethics and project management, Biological engineering professional English, etc.
	上游技术 Upstream of biotechnology	合成生物学、工业微生物育种、DNA 重组与分子克隆实训 Synthetic biology, Industrial microorganism breeding, DNA recombination and molecular cloning training

形成：
围绕上中下游技术、非技术典型能力项，通过理论、案例与工程实践初步形成复杂工程问题分析和解决问题的能力

(待续)

(续表 4)

能力培养阶段 Ability development stages	课程模块 Curricula modules	课程 Curricula
Forming period: focusing on the upper, middle and downstream of biotechnical and non-technical typical capabilities, the ability to analyze and solve complex engineering problems is preliminarily formed through theories, cases and engineering practice	中游技术 Midstream of biotechnology	发酵工程原理、酶工程与生物催化、生物反应工程与设备、生物工程设备设计、生物工厂设计、化工原理课程设计、发酵工艺综合实训等 Principles of fermentation engineering, Enzyme engineering and biocatalysis, Bioreactor engineering and equipment, Biological engineering equipment Design, Biological plant design, Chemical engineering unit processes design, Fermentation process comprehensive training, etc.
	下游技术 Downstream of biotechnology	生物分离工程、生物活性大分子制备创新与分离纯化实践、现代仪器分析、生物药物分析等 Bioseparation engineering, Preparation innovation and separation and purification practice of bioactive macromolecules, Modern instrument analysis, Biopharmaceutical analysis, etc.
	沟通与管理 Communication and Management	写作与表达、工程伦理与项目管理、药事管理学、生物技术经济学、EHS 管理体系等 Writing and expression, Engineering ethics and project management, Pharmaceutical management, Biotechnology economics, EHS management system, etc.
运用: 依托项目创新实训、企业情境训练、实习和毕业设计(论文), 综合运用知识、技能解决真实和模拟情境下的专业复杂工程问题 To use: relying on project innovation training, enterprise situational training, internship and graduation project (thesis), the company comprehensively uses knowledge and skills to solve professional complex engineering problems in real and simulated situations	项目化训练与课题研究 Project training and research	生物工程项目化创新实训、专业实习、毕业实习、医药生物技术学院企业训练课程、毕业设计(论文) Bioengineering project innovation training, Professional practice, Graduation practice, Enterprise training courses of College of Medicine and Biotechnology, Graduation design (thesis)

上述课程体系自 2018 年开始实行。以此为基础,本专业将支撑课程的课程目标瞄准解决代表性复杂工程问题能力的培养,根据能力培养的孕育-形成-运用 3 个不同阶段设置课程目标。通过现代产业学院运行模式引入合作企业专业师资、实施教师科研反哺教学、项目化驱动实践、校企课程共建共享、学生专业社团活动、企业真实情境学习等活动,促进构建具有创新性、综合性和挑战度的课程,较好地支撑了解决复杂工程问题能力的培养。

5 总结

复杂工程问题能力培养是工程教育产出导向的重点。深入分析与认识专业领域和专业岗位相关的复杂工程问题的特点与内涵是进一步制订专业毕业要求,设计培养方案、课程体系的重要基础,也是指导课程建设、课程实施和课程改革的重要依据。本文依照工程教育认证的理念和要求,根据对毕业生、企业和市场调查的结果,梳理了长三角地区对生物工程类专业本科毕业生主要专业技术岗位的需求与要求,分解了典型能力项,分析和吸收了利益相关方的众多意见建议,凝练了生物工程专业应用型本科层次人才典型工作岗位的代表性复杂工程问题,形成了本专业 2018 版培养方案中解决复杂工程问题能力培养的课程体系。经过连续 3 年的实践,各门课程目标不断围绕人才培养的毕业要求,对标解决复杂工程问题能力的培养,利用区域产业资源优势,通过医药生物技术学院建设广泛引入产业界前沿教育资源、教师科研反哺教学项目建设、课程团队与一流课程同步建设、覆盖全员的学生专业社团建设等多种措施进行教学改革,学生的培养质量逐年提高。生物产业正进入快速发展的阶段,如何更好地培养满足业界需求的高素质应用型人才,还需要不断依照工程教育认证的理念和方法体系持续完善。

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