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Teaching Chemistry in the New Bachelor *"Regenerative Medicine and Technology"*

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Abstract: Regenerative Medicine (RM) is a multidisciplinary field uniting science, technology, and entrepreneurship to develop curative health solutions. In response to labor market demand, Maastricht University (UM) has launched an undergraduate program, Regenerative Medicine and Technology (BSc RMT), integrating natural sciences engineering, and medicine. Teaching at UM follows the principles of Problem-Based Learning (PBL) and Research-Based Learning (RBL). In line with this philosophy, chemistry in the BSc RMT is taught contextually within multidisciplinary courses. Students apply chemical concepts to biological and materials science challenges, supported by small-group tutorials, problem-solving sessions, and hands-on labs. Despite challenges - such as heterogeneous student backgrounds, limited resources, and restricted lab time - the program shows promising outcomes in performance and engagement. Teaching chemistry in this setting requires balancing depth with relevance and supporting instructors across disciplinary boundaries. This initiative demonstrates how contextual, interdisciplinary education fosters molecular-level understanding and prepares students for future roles in RM.

Keywords: higher education, STEM education, chemistry education, multidisciplinary education, regenerative medicine.

INTRODUCTION

SCIENCE is becoming increasingly multidisciplinary and societal impact often requires bridging science, technology, entrepreneurship and other fields.[1–4] Regenerative Medicine (RM) is such a multidisciplinary field in which science, technology, and entrepreneurship are overarched to advance healthcare and eventually economy.[5–11] RM attempts to replace, mimic or recreate human cells with the aim of recovering diseased or damaged cells, tissues and organs. Ultimately, RM-based approaches aim to cure and eventually eradicate diseases as opposed to merely treating symptoms.

RM is a highly multidisciplinary field bringing together engineering and technology, anatomy and physiology, biology, chemistry and materials, data science and modelling, and entrepreneurship (Fig. 1).[10,11] New and upcoming fields like RM, and the corresponding new research profiles (backed up by labor market research), require new teaching approaches.[12–16] The challenge is how to introduce new multidisciplinary fields while maintaining a solid foundation.[14] How can we teach students in a more efficient way than how we were once trained? How do we transfer our knowledge, skills and experience to younger generations? Our approach was to launch a new Bachelor program Regenerative Medicine and

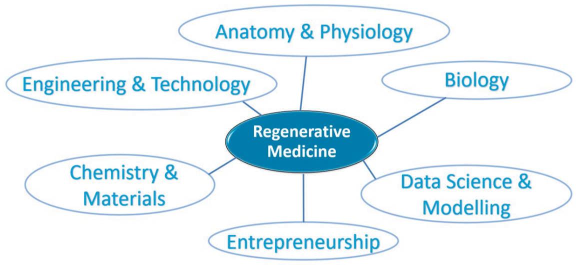

Figure 1. A schematic illustration of the field of RM and contributing disciplines and fields.

Technology (BSc RMT) to provide the graduates with the necessary foundation to be active in the field and grow into future change-makers.[17] The vision is to produce graduates who can design, develop, evaluate and market novel medical therapies and devices based on regeneration; the graduates are envisaged to become researchers, engineers or entrepreneurs, and not medical practitioners. With its broad scientific and engineering basis, chemistry is an important pillar in the program (and in the field).

The challenge is how to effectively teach chemistry in such a multidisciplinary program, and how to balance breadth and depth. At Maastricht University (UM) we rely on the philosophy of Problem-Based Learning (PBL) which rests on the principles of constructive, contextual, collaborative and self-directed learning.[18–24] In combination with Research-Based Learning (RBL),[25] this approach lends itself excellently to teaching in a multidisciplinary context.

APPROACH

In response to the demand of the labor market, in September 2023 the UM launched a novel undergraduate program RMT,[17] which has since demonstrated growth, and is now in the process of recruiting its third cohort of students. As the first step of the curricular design, a total of three competencies were defined (Table 1): Scientist and Engineer (S&E), Researcher & Designer (R&D), and Professional & Communicator (P&C). These were then further specified into fourteen final qualifications (FQs) (Table 1) which were then in turn translated into a curriculum (Fig. 2). This backward design[26,27] was conducted adhering to the principles of constructive alignment.[28]

The curriculum comprises three study years with the first two years introducing RM-content, and the third year in which students follow a minor and take on a graduation research project. The first two years are organized in six academic periods with recurring topics (see colored backgrounds in Fig. 2). Each period the students follow a multidisciplinary course and three longitudinal lines. The

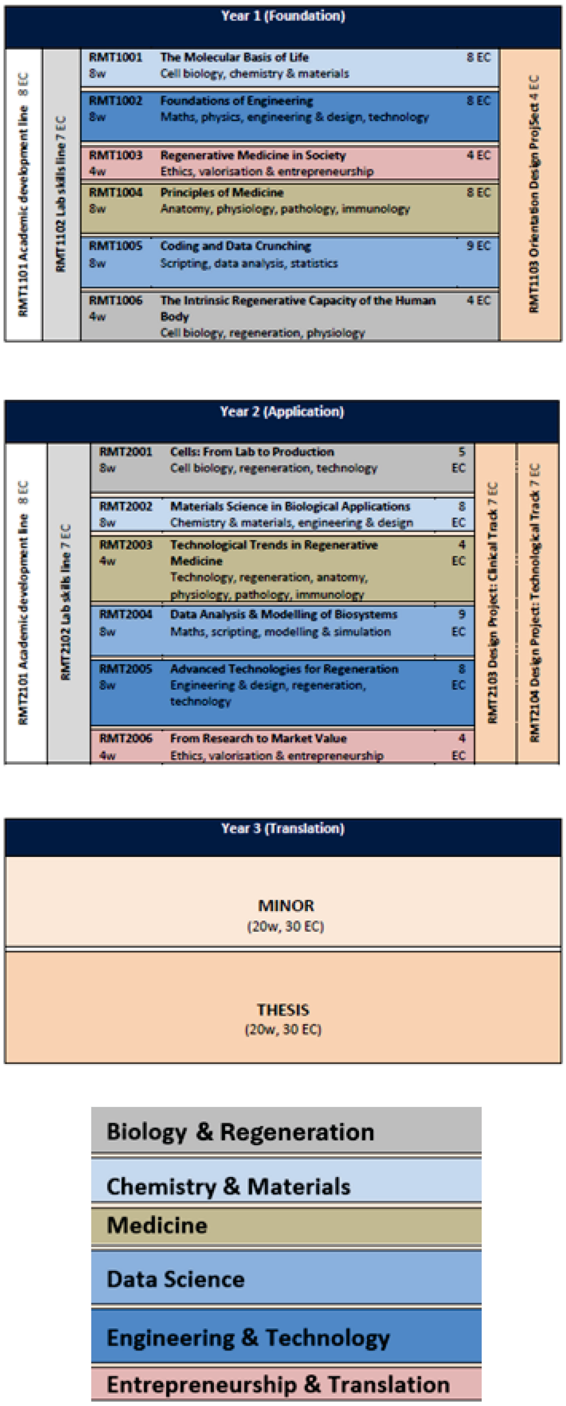

Figure 2. A curriculum map for the BSc RMT program at the UM, including module codes. The academic years are organized in six periods following an 8+8+4 week (w) pattern each semester. Thematiclly related periods are highlighted in the same color; Biology & Regeneration, Chemistry & Materials, Medicine, Data Science, Engineering & Technology, Entrepreneurship & Translation. EC = European Credits.

Table 1. An overview of the BSc RMT Competencies (highlighted in bold) and the corresponding derived Final Qualifications (FQs). S&E 3 and 7 refer to the chemistry- and materials-related content in the curriculum.

Competencies and FQs[(a)]	The graduate/student:
S&E	**Has knowledge and understanding of the relevant central concepts in the fields of natural sciences, engineering and medicine, and can apply these concepts in the interdisciplinary field of regenerative medicine.**
S&E 1	Recognises, describes and applies the key principles and various technologies of regenerative medicine.
S&E 2	Is able to explain, illustrate and propose the potential of regenerative medicine for addressing the limitations and challenges of contemporary medicine.
S&E 3	Has knowledge and understanding of the basic concepts of cell biology and chemistry and is able to apply these to develop technology for regenerative medicine.
S&E 4	Is able to describe the basic concepts of medicine and medical technologies, and makes use of these to develop technology for applications in regenerative medicine.
S&E 5	Has knowledge and understanding of the basic concepts of mathematics and statistics, and makes use of these to develop technology for applications in regenerative medicine, to design experiments and to analyse collected data.
S&E 6	Demonstrates a comprehension of basic concepts of data and computational science, and applies these in regenerative medicine.
S&E 7	Explains basic concepts of physics, engineering and materials science, and makes use of these to develop technology for applications in regenerative medicine.
S&E 8	Values and justifies the strengths and relevance of individual disciplines but is also able to transcend individual disciplines to address research and/or design challenges in regenerative medicine.
R&D	**Develops critical thinking and problem-solving skills, learns to be inquisitive and to explore, and select appropriate methodologies in order to contribute to innovative products and/or therapies suitable for addressing clinical or biomedical problems.**
R&D 1	Is able to independently apply relevant laboratory skills and techniques to conduct research in regenerative medicine.
R&D 2	Understands, appreciates and critically assesses the process of scientific research to obtain academic knowledge and insight, and is able to draw conclusions based on evidence in a logically structured fashion.
R&D 3	Readily evaluates, selects and applies scientific methodology and available technology to address current challenges and problems in regenerative medicine or in a related biomedical field, and contributes to finding an innovative solution.
R&D 4	Based on obtained research results or applied technologies, contributes to the realisation of novel, innovative and marketable clinical or biomedical products/therapies.
P&C	**Organises work and research activities efficiently and effectively, in line with current ethical and societal standards and adjusted to context. Is able to collaborate in a diverse team, takes responsibility for ongoing personal and academic development, and can disseminate knowledge and findings to diverse audiences.**
P&C 1	Organises study, work and research efficiently and effectively, and within given time constraints.
P&C 2	Shows awareness of various team roles, functions efficiently in multidisciplinary and otherwise diverse teams, values diversity in a broader sense, and takes into account ethical standards and societal, economic and regional and global contexts.
P&C 3	Communicates professionally and adjusts style and type of communication and argumentation to the audience and the occasion.
P&C 4	Self-reflects, is aware of the working environment, forms and expresses own opinions, takes responsibility for own personal and academic growth and development, and embraces lifelong learning.

[(a)] S&E = Scientist & Engineer, R&D = Researcher & Designer, P&C = Professional & Communicator.

longitudinal lines are year-long modules which train the students in developing skills; academic skills, laboratory skills, and research and design skills. The lines are topically aligned with the courses. Each module - whether a course or a longitudinal line - is developed and coordinated by a multidisciplinary course-planning group (CPG) consisting of 3–7 members, typically 4–5. The multidisciplinary character of a CPG is ensured by selecting members from different institutes and, in some cases, from different faculties. The CPGs are typically composed of members representing different levels of seniority.

The BSc RMT program is offered by the Faculty of Health, Medicine and Life Sciences (FHML) and the entry requirements for the program are biology, chemistry, physics, and mathematics. There is no entry exam but students are required to have these four subjects (with a pass) on their secondary school diploma, and their level needs to be comparable to that of the Dutch pre-university secondary schools.[29–32]

In the RMT curriculum, chemistry is mostly represented in the courses RMT1001 The Molecular Basis of Life, RMT2002 Materials Science in Biological Applications, and the RMT1102 and RMT2102 Lab Skills Line in the corresponding periods. The course and line syllabi, including extensive course descriptions and the corresponding intended learning outcomes (ILOs), can be found in the Supporting Information. In Year 1 students mostly get introduced to chemistry in the context of biochemical

Table 2. An overview of biological systems and biochemical processes of relevance for the RM field used in teaching chemistry concepts in the RMT1001 course of the BSc RMT program.

Week	Biological systems, processes and concepts	Subarea of chemistry	Chemistry concepts	Selected examples
1	Cellular signalling	General chemistry	Chemical bonds, molecular structures, supramolecular interactions, structure-property relationships	Structures of signalling molecules, interactions between signalling molecules and receptors
2	Extracellular matrix	General chemistry	Molecular structure, solution-phase chemistry, acids and bases, structure-property relationships	Amino acids, buffers
3	Stem cells, connective tissue regulation and repair	Inorganic chemistry	Crystalline and amorphous materials, nanoparticles, structure-property relationships	Hydroxyapatite and calcium phosphates, bioglasses and ceramics
4	Spatiotemporal regulation of cell fate	Organic chemistry	Functional groups, stereochemistry, isomerism, polymers, biological molecules, structure-property relationships	Amino acids, proteins, proteoglycans and glycoproteins, carbohydrates, lipids, nucleic acids, hormones
5	Regulation of the cell cycle	Organic chemistry	Reactivity, organic transformations, selectivity, relevant biochemical reactions	Phosphorylation and hydrolysis, peptide bond formation and hydrolysis
6	Macromolecular structural organization in tissues	Analytical chemistry	Measurements, spectroscopies and spectrometries, structure-property relationships	UV-Vis Spectrophotometry for bone analysis
7	Regenerative medicine in clinical practice	Physical chemistry	Chemical kinetics, thermodynamics, structure-property relationships	Quantifying drug release, enzymes, mechanism of phosphorylation by kinases, quantifying ligand-receptor equilibria, shifting equilibrium in synthesis of a PLA biomaterial

Table 3. An overview of the chemistry concepts taught, expanded and/or applied in the RMT2002 course of the BSc RMT program, including examples of relevance for the RM field.

Week	Materials science concepts	Subarea of chemistry	Chemistry concepts	Selected examples
1	Polymer materials, biomaterials, biocompatibility, thermosets *vs* thermoplasts, glass-transition temperature	Polymer chemistry	Polymers, tacticity, (average) molecular weights, weight distribution, mass spectrometry, chromatography, structure-property relationships	Mimicking extracellular matrix, gel permeation chromatography, functionalization with RGD
2	Characterization and properties of biomaterials	Analytical chemistry, polymer chemistry	Spectroscopy, spectrometry, calorimetry, structure-property relationships	Young's modulus, NMR, IR, DSC, live-dead tests
3	Organic and polymer biomaterials	Organic chemistry, polymer chemistry, supramolecular chemistry	Polymerization mechanisms, supramolecular polymers, crosslinking, structure-property relationships	Dynamically crosslinked polymers, hydrogels, biomimetic materials, PLA synthesis, biodegradability
4	Inorganic biomaterials	Inorganic chemistry, nanochemistry	Metals, crystallinity, composites, interactions, structure-property relationships	Metal implants, calcium phosphate ceramics for bone regeneration, bioglasses
5	Biological biomaterials	Organic chemistry, biochemistry, polymer chemistry	Natural *vs* synthetic materials, biopolymers	Living materials, synthetic modifications, decellularized extracellular matrix, recombinant proteins, collagen biosynthesis
6	Cell-material interactions	Organic chemistry, polymer chemistry, medicinal chemistry, nanochemistry	Local drug delivery, drug-delivery nanovehicles, dendrimers	Targeted therapeutics, (coated) drug-eluting stents, biodegradation, drug-loaded liposomes
7	Advanced technologies	Chemical engineering, supramolecular chemistry, organic chemistry, polymer chemistry	Material processability and fabrication, click chemistry, machine learning and AI in chemistry	Genetic editing, 3D-printing, bioprinting, biofabrication, electrospinning, photolithography, creation of organoids, cyclodextrines

processes of relevance to cellular signaling, stem-cell differentiation and tissue growth; chemistry is therefore strongly intertwined with (stem-)cell biology. In that context the basic concepts of general, inorganic, organic, analytical and physical chemistry are introduced and built upon the secondary school knowledge which the students are already expected to have as secondary school chemistry is one of the entry requirements to enroll in the program. Examples of relevant biological systems and/or biochemical processes used to introduce chemistry concepts are summarized in Table 2. The intention is to help students develop the ability to view and discuss biological systems and processes at the molecular, cellular and organ levels (see course ILOs in the course syllabus in the Supporting Information, and the FQ S&E 3 in Table 1). In Year 2 the students apply the chemistry knowledge from Year 1 to biomaterials which is one of the pillars of the field of RM. The chemistry is now not only intertwined with biology but also with engineering and technology. Students learn how to think about materials at the molecular and processing levels (see course ILOs in the course syllabus in the Supporting Information, and the FQs S&E 3 and 7 in Table 1). They also further expand on their knowledge of organic and inorganic chemistry as part of learning about organic, inorganic and biological materials for the use in RM and other biomedical applications. Table 3 illustrates how some of the chemistry concepts are integrated into relevant examples and concepts in biomaterials.

Maybe even more important than which chemistry concepts are taught in the BSc RMT, is how these are taught. As mentioned earlier, the UM has pioneered in the PBL approach in which constructive, contextual, collaborative and self-directed learning are central.[18,19] In practice, this means that there are 12 contact hours weekly on average and very few lectures (an average of 2 hours per week), and that most teaching and learning activities are conducted in small(er) groups. The courses RMT1001 and RMT2002 offer a variety of activities (Table 4). Interactive *lectures* are given to the whole group of students and recorded for study purposes. The purpose of the lectures is to introduce new concepts and link them to previously learned topics and concepts; they also give guidance to how much content depth is required in the course. *Tutorials* are conducted in student groups of 12 and supervised

Table 4. An overview of teaching activities in courses RMT1001 and RMT2002, presented per week.

Week	RMT1001	RMT2002
1	Course Opening Lecture (1 x 1 hour) Lectures (2 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) ChemOffice Workshop (1 x 2 hours)	Course Opening Lecture (1 x 1 hour) Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours)
2	Lectures (3 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) ChemOffice Workshop (1 x 2 hours)	Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) ChemOffice Workshop (1 x 2 hours)
3	Lectures (2 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours)	Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours)
4	Lectures (2 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) Introduction to Group Assignment (1 x 1 hour) Midterm Mock Exam (1 x 2 hours)	Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) Introduction to Group Assignment (1 x 1 hour) Midterm Mock Exam (1 x 2 hours)
5	Lectures (2 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) ChemOffice Workshop (1 x 2 hours)	Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) ChemOffice Workshop (1 x 2 hours)
6	Lectures (2 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours)	Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours)
7	Lectures (2 x 1 hour) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours)	Lectures (1 x 2 hours) Tutorials (1 x 2 hours) Problem-Solving Sessions (1 x 2 hours) Guest Lecture (1 x 1 hour)
8	Q&A (1 x 2 hours) Written Exam (1 x 2 hours) Mini-symposium (1 x 2 hours)	Q&A (1 x 2 hours) Written Exam (1 x 2 hours) Mini-symposium (1 x 2 hours)

by a tutor. In these sessions students read a case for that week, discuss what it is about and define learning goals for that week ("pre-discussion"). The week after they discuss what they have learned by means of self-study, and they exchange findings ("post-discussion"). Then the students read another case and the process continues. The role of the tutor is not that of a content expert but rather to manage the discussion and the process. The weekly cases may be found in the syllabi of the RMT1001 and RMT2002 courses in the Supporting Information. *Problem-solving sessions* are given in groups of 20 students in the presence of a content expert (chemist). The students are grouped into smaller groups, and discuss and solve short problem-sets which require drawing molecules, performing calculations, etc. The *ChemOffice workshops* are given for the whole group of students with multiple instructors and are aimed at introducing students to the software, helping them visualize molecules and stimulating them to use it during their studies (for preparing lab reports, presentations, etc).

Both courses also feature a group assignment in which students work in groups of 3 to 4 to create something new. In RMT1001 students are asked to design a new multidisciplinary tutorial case of relevance to regenerative medicine, with chemistry and biology learning goals. Students present the case as a one-pager and in an oral presentation which is assessed for the content. In RMT2002 students are asked to propose a design of a novel biomaterial that is expected to solve a clinical problem or to propose a valid research strategy. Students present their proposal in a two-pager and in an oral presentation in which they also defend their idea in front of an audience of peers and teaching staff. Detailed descriptions of the group assignments are available in the corresponding course syllabi in the Supporting Information, along with the corresponding assessment rubrics.

In RMT1001 and RMT2002 student learning progress is assessed at the end of the course in form of a written exam with case-like open-ended questions (75 % of the final course grade) and a group oral presentation (25 % of the final course grade). A passing grade is required for both assessments.

OUTCOME AND OUTLOOK

The passing rates in RMT1001 (after the opportunity for a resit) were 87 % (2023-2024) and 80 % (2024-2025), and in RMT2002 100 % (2024-2025). High passing rates in Year 2 (following the opportunity for a resit) are not uncommon. In the absence of a formal program admission examination - and given the requirement of a secondary school diploma - Year 1 effectively functions as a selection mechanism for identifying students who are well-suited to the program. Those who progress to Year 2 typically possess both the requisite skills and the motivation to successfully complete the remainder of the curriculum.

The student evaluations have in general been positive (student evaluations of RMT1001 and RMT2002 in their first running years are provided in the Supporting Information). Students report being satisfied with the content and how chemistry is integrated with other disciplines. They also report their appreciation of the diverse activities in the courses.

In RMT1001, however, the students have perceived some misalignment between the problem-solving sessions and other activities in the course. This has to do with the fact that in the problem-solving sessions students were asked to practice exercises and problems from a chemistry textbook while in other activities, including the exam, the students were asked to discuss chemistry in the context of cases relevant to the field of regenerative medicine. In response to the feedback received, at the moment we are in the process of developing problem sets tailored to the context of our study. Given the fact that there are no textbooks focusing on chemistry in the field of regenerative medicine, we need to develop these materials from scratch which is quite laborious. However, we believe that these new materials will not only stimulate contextual learning but also increase student engagement in the course; this will hopefully also be reflected in the success rates.

Besides reporting passing rates and student evaluations, we also aim to illustrate students' learning success by examining the ILOs of the first-year course RMT1001 and their role in preparing students for the second-year follow-up course RMT2002. The latter assumes a foundational understanding of general, inorganic, organic, analytical, and physical chemistry, as well as stem cell biology and associated biochemistry. For this illustration, we focus on RMT1001's ILO10 (see Supporting Information for the course syllabus with a complete list of ILOs): "Upon completion of this course, the student is able to elaborate how the learned basic concepts of general, physical, organic, and inorganic chemistry can be applied to understand biological processes and to design materials for biomedical applications with specific physico-chemical properties." This ILO exemplifies the curriculum's intention to construct knowledge, in line with the constructivist principle of problem-based learning.[18,19] In RMT1001, the emphasis is on understanding biological processes related to regeneration with introductory links to biomaterials, whereas RMT2002 builds on this foundation and focuses on biomaterial design.

Table 5 illustrates how constructive alignment is realized for this ILO across the two courses. It shows how intended outcomes are translated into concrete learning activities, such as small-group tutorials, interactive lectures, and assignments, and how these are assessed through group work and exam questions. The example

Table 5. Constructive alignment of RMT1001 and RMT2002 illustrated through ILO10: RMT1001 builds foundational links between chemistry and biology, while RMT2002 advances this knowledge toward biomaterial design.

Course	Intended Learning Outcome (ILO)	Learning Activities	Assessment Examples
RMT1001	ILO10: Upon completion of this course, the student is able to elaborate how the learned basic concepts of general, physical, organic and inorganic chemistry can be applied to understand biological processes and to design materials for biomedical applications with specific physico-chemical properties.	• Discussing and solving multidisciplinary cases (small-group tutorials) • Designing and working out an own multidisciplinary case (group assignment) • Demonstrating and discussing links between chemistry and biology concepts (interactive lectures) • Practicing chemistry exercises and applying concepts in RM-contexts (problem-solving sessions) • Visualizing molecules and reactions of relevance to RM (ChemOffice workshops)	• Assessment Criterion: Multidisciplinary character of the case (group assignment) • Example exam question 1: Name the major organic and inorganic constituents of bone and explain which contributes to its tensile and which to its compressive strength. (as part of an exam case) • Example exam question 2: How do these two constituents (see question 1) interact with each other at the molecular level? Which (supramolecular) interactions are there, and which groups do they involve? (as part of an exam case)
RMT2002	Builds upon ILO10: Assumes understanding of chemistry–biology interface and applies it to biomaterial design.	▪ Discussing and solving multidisciplinary cases (small-group tutorials) ▪ Designing a novel biomaterial to address a clinical need (group assignment) ▪ Demonstrating and discussing links between chemistry, materials engineering and biology concepts (interactive lectures) ▪ Practicing with chemistry and materials concepts in RM and broader biomedical contexts (problem-solving sessions) ▪ Visualizing macromolecules and reactions of biomedical and RM relevance (ChemOffice workshops)	▪ Assessment Criterion: Presence and quality of insights into regenerative medicine – a multidisciplinary solution (group assignment) ▪ Example exam question 1: Which material properties play a role in cell attachment? Which modifications would you make to the material surface to enhance these properties? (as part of an exam case) ▪ Example exam question 2: For bone substitute materials, an appropriate porosity is essential for cell migration, adhesion, tissue formation and nutrient diffusion. Propose a suitable fabrication method to achieve this porosity. How would you ensure control over the resulting microstructure? (as part of an exam case)

highlights the progression from RMT1001, where students integrate basic chemistry and biology concepts in the context of regenerative medicine, to RMT2002, where they apply this foundation to the design of biomaterials. The successful completion of RMT2002 demonstrates that RMT1001 effectively prepares students for the follow-up course. Combined with positive feedback from RMT2002 teachers, this provides strong evidence of the pedagogical success of this constructive alignment in fostering multidisciplinary competencies.

REMAINING CHALLENGES

Teaching chemistry in such a multidisciplinary and international program comes with a number of challenges. Teachers are faced with very heterogeneous student groups in terms of the knowledge they bring from secondary school. Very few students are equally knowledgeable and/or interested in all four disciplines required to enroll in the program. What is more, not all students have covered exactly the same topics, and not to the same extent, during their secondary education. Due to the highly multidisciplinary nature of the program, it is practically impossible to repeat everything from secondary school for all four scientific disciplines. We do use textbooks that allow students to refresh some aspects of their secondary education, but this is often left up to the students so not all students will be equally proactive in this. We are now working on the development of a refresher package which the students could use for this purpose.

Developing such a multidisciplinary program, and teaching in it, is also difficult given that most teachers have a monodisciplinary background.[33] We strive to make our students feel comfortable in all disciplines of science while we ourselves often do not feel the same way. We wish to train students in a new and different way of thinking. Trying to achieve this takes a CPG and teachers a lot of time and effort. Aligning content is the crucial step. For example, in RMT1001, each biology-focused lecture (given by a biologist) is followed by a chemistry-focused lecture (given by a chemist), with explicit links emphasized between the two. We also do not wish to teach chemistry for the sake of chemistry but clearly show the direct relevance of each concept in the field of RM. Achieving this integration, however, is time-intensive and requires that sufficient time be allocated for this by administration. Another example involves the multidisciplinary cases in which chemistry and biology are interwoven in the context of RM. A major challenge is the scarcity of suitable teaching materials, as there are currently no textbooks in regenerative medicine that cover the chemical (molecular) aspects of relevant systems and processes in sufficient detail. This turns teachers into students, as they are also forced to learn more about the other disciplines. Teachers often perceive teaching in such an environment as tedious but also rewarding. This is not characteristic of the chemistry-heavy courses but of the entire BSc RMT program. Every course and longitudinal line has been deliberately designed to be multidisciplinary, and was developed and is now coordinated by a multidisciplinary CPG. Thematically, this approach has facilitated the development and coordination of modules. However, many CPGs report that it takes considerable time and effort before all members learn to speak the “same language.” Courses like this also require development of new content, as multidisciplinary textbooks and suitable teaching content are not available at the moment. Compared to more traditional programs, in which each module is coordinated by a single teacher, we believe that our approach requires greater investment but also results in a more diverse and multifaceted curriculum.

Multidisciplinarity is reflected in all aspects of the courses and therefore also in the assessment. The written exam questions in RMT1001, for example, are based on two multidisciplinary cases in RM, with biology- and chemistry-focused questions contributing an equal weight of points and all being strongly related to the case. In line with the intended learning outcomes of RMT1001 (see course syllabus in the Supporting Information), these questions do not test isolated disciplinary knowledge but rather assess whether students can apply fundamental principles of chemistry (ILOs 1, 2, 9) and biology (ILOs 3, 4, 6, 8) in an integrated manner. Moreover, several ILOs are themselves multidisciplinary in nature—such as ILO3 (cell–matrix interactions), ILO4 (linking cell biology and biochemistry), ILO5 (structure and function of biomolecules), ILO7 (tissues at chemical and biological levels), and especially ILO10 (applying chemistry to understand biological processes and design biomaterials). These outcomes explicitly require students to combine perspectives across disciplines rather than master them in isolation. This is also in line with the program’s final qualification S&E 3 (Table 1). Accordingly, the exam structure reflects this integration: it allows students to demonstrate that they have achieved the required multidisciplinary competencies, even if their performance in one discipline is weaker than in the other. More concretely, we do see that some students struggle with chemistry but nevertheless demonstrate the competencies required by the learning outcomes and therefore succeed in the exam. To chemists, this may feel unjust; however, teachers also need to accept that these students are not chemistry majors and are instead expected to demonstrate a balanced, application-oriented knowledge base that combines both chemistry and biology in the service of regenerative medicine.

The teaching philosophy at the UM is based on the principles of PBL.[18] At our faculty (FHML), this translates to an average of 12 contact hours per week. While this framework works well with conveying theoretical concepts, teaching laboratory skills remains challenging. As chemists, we are used to full days in the lab and would like to train our students in a similar way. However, in the BSc RMT we have an average of 4 hours per week at our disposal for lab trainings. This means that experiments need to be designed accordingly and that students do not have the luxury of making too many mistakes and learning from them. That said, our students report being very happy with lab work and with putting theory into practice.

CONCLUSION

The Bachelor program in Regenerative Medicine and Technology (BSc RMT) at Maastricht University has been developed in response to the increasing demand for professionals capable of operating at the intersection of science, technology, health sector and entrepreneurship. Regenerative medicine (RM), a highly multidisciplinary field aiming to restore or replace damaged tissues and organs, forms the foundation of this program. Chemistry is an important aspect of the program and is introduced in multidisciplinary modules together with biology and elements of engineering. Following the approach of Problem-Based Learning (PBL), content is introduced through context-rich, problem-based and research-based learning approaches, aiming to connect molecular-level understanding with real-world biomedical applications. The courses are designed with diverse and interactive teaching methods, including tutorials, group assignments, problem-solving sessions, and practical workshops. While teaching chemistry in this setting presents challenges—such as diverse student backgrounds, limited teaching materials, and time constraints for lab work—the program has been well received by students and shows promising early outcomes.

This new approach to teaching chemistry within a multidisciplinary program reflects a broader shift in science education, where relevance, integration, and student-centered learning take precedence. By focusing on contextual learning and aligning chemistry with practical biomedical challenges, the BSc RMT not only equips students with essential knowledge but also prepares them to become adaptable professionals capable of driving innovation in regenerative medicine. Although there are clear hurdles - ranging from teacher readiness to resource limitations - the enthusiasm of both students and educators suggests a strong foundation for future refinement and growth.

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Supplementary Information. Supporting information to the paper is attached to the electronic version of the article at: https://doi.org/10.5562/cca4185.

PDF files with attached documents are best viewed with Adobe Acrobat Reader which is free and can be downloaded from Adobe's web site.

REFERENCES

[1] P. D'Este, N. Robinson-García, *Res. Policy* **2023**, *52*, 104609. https://doi.org/10.1016/j.respol.2022.104609

[2] P. E. Smaldino, C. O'Connor, *Collect. Intell.* **2022**, *1*, 26339137221131816. https://doi.org/10.1177/26339137221131816

[3] L. Waltman, A. F. J. van Raan, S. Smart, *PLoS ONE* **2014**, *9*, e111530. https://doi.org/10.1371/journal.pone.0111530

[4] M. Alber, A. Buganza Tepole, W. R. Cannon, S. De, S. Dura-Bernal, K. Garikipati, G. Karniadakis, W. W. Lytton, P. Perdikaris, L. Petzold, E. Kuhl, *npj Digit. Med.* **2019**, *2*, 115. https://doi.org/10.1038/s41746-019-0193-y

[5] H. L. Greenwood, P. A. Singer, G. P. Downey, D. K. Martin, H. Thorsteinsdóttir, A. S. Daar, *PLoS Med.* **2006**, *3*, e381. https://doi.org/10.1371/journal.pmed.0030381

[6] K. L. McKinley, M. T. Longaker, S. Naik, *Science* **2023**, *380*, 796–798. https://doi.org/10.1126/science.add6492

[7] D. J. Polak, *J. R. Soc. Interface* **2010**, *7*, S777. https://doi.org/10.1098/rsif.2010.0362.focus

[8] A. E. Altyar, A. El-Sayed, A. Abdeen, M. Piscopo, S. A. Mousa, A. Najda, M. M. Abdel-Daim, *Biomed. Pharmacother.* **2023**, *158*, 114131. https://doi.org/10.1016/j.biopha.2022.114131

[9] J. Wang, G. Deng, S. Wang, S. Li, P. Song, K. Lin, X. Xu, Z. He, *Front. Neuroscie.* **2024**, *18*, 1269577. https://doi.org/10.3389/fnins.2024.1269577

[10] N. J. Willett, M. L. Boninger, L. J. Miller, L. Alvarez, T. Aoyama, M. Bedoni, K. A. Brix, C. Chisari, G. Christ, C. L. Dearth, T. A. Dyson-Hudson, C. H. Evans, S. M. Goldman, K. Gregory, A. Gualerzi, J. Hart, A. Ito, H. Kuroki, M. T. Loghmani, D. L. Mack, *Arch. Phys. Med. Rehabil.* **2020**, *101*, 917–923. https://doi.org/10.1016/j.apmr.2020.01.007

[11] V. Cheuy, S. Picciolini, M. Bedoni, *npj Regen. Med.* **2020**, *5*, 16. https://doi.org/10.1038/s41536-020-00102-2

[12] W. James Jacob, *Palgrave Commun.* **2015**, *1*, 15001. https://doi.org/10.1057/palcomms.2015.1

[13] J. E. Schijf, G. P. C. van der Werf, E. P. W. A. Jansen, *Eur. J. High. Educ.* **2022**, *13*, 429–447. https://doi.org/10.1080/21568235.2022.2058045

[14] M. W. C. Vereijken, S. Akkerman, S. Susan, I. Iris, M. Kluijtmans, *High. Educ. Res. Dev.* **2022**, *42*, 1762–1775. https://doi.org/10.1080/07294360.2022.2156482

[15] D. Ripley, L. Markauskaite, *High. Educ.* **2024**. https://doi.org/10.1007/s10734-024-01360-5.

[16] J. Shah, *J. Electr. Syst.* **2024**, *20*, 2060. https://doi.org/10.52783/jes.2309

[17] Bachelor Regenerative Medicine and Technology (accessed 22nd May 2025) https://curriculum.maastrichtuniversity.nl/education/bachelor/bachelor-regenerative-medicine-and-technology

[18] Problem-Based Learning at Maastricht University (accessed 22nd May 2025) https://www.maastrichtuniversity.nl/over-de-um/onderwijs-aan-de-um/problem-based-learning

[19] Core Principles of PBL (accessed 22nd May 2025) https://www.maastrichtuniversity.nl/about-um/education-at-um/edlab/core-principles-pbl-constructive-collaborative-contextual-and-self

[20] H. G. Schmidt, *Med. Educ.* **1983**, *17*, 11–16. https://doi.org/10.1111/j.1365-2923.1983.tb01086.x

[21] H. G. Schmidt, *Med. Educ.* **1993**, *27*, 422–432. https://doi.org/10.1111/j.1365-2923.1993.tb00296.x

[22] A. M. A. E. Sayary, S. A. Forawi, N. Mansour In *The Routledge International Handbook of Research on Teaching Thinking* (Eds.: R. Wegerif, L. Li, J. C. Kaufman), Routledge, London, **2015**, pp. 381–392.

[23] K. Smith, N. Maynard, A. Berry, T. Stephenson, T. Spiteri, D. Corrigan, J. Mansfield, P. Ellerton, T. Smith, *Educ. Sci.* **2022**, *12*, 728. https://doi.org/10.3390/educsci12100728

[24] A. N. Mansor, N. O. Abdullah, J. Abd Wahab, M. S. Rasul, M. Y. Mohd Nor, R. A. Raof, *Asian Soc. Sci.* **2015**, *11*, 259. https://doi.org/10.5539/ass.v11n4p259

[25] S. Sulistyo, S. Saputro, W. Sunarno, S. Sukarmin, *Eur. J. Educ. Res.* **2021**, *10*, 1051. https://doi.org/10.12973/eu-jer.10.3.1051

[26] G. Wiggins, J. McTighe, *Understanding by Design*, Expanded 2nd ed.; Association for Supervision and Curriculum Development: Alexandria, Va., **2005**.
[27] K. Y. Neiles, K. Arnett, *J. Chem. Educ.* **2021**, *98*, 2829–2839. https://doi.org/10.1021/acs.jchemed.1c00443
[28] J. Biggs, *High. Educ.* **1996**, *32*, 347–364. https://doi.org/10.1007/BF00138871
[29] Examenblad Biologie 2025 (accessed 23rd May 2025) https://www.examenblad.nl/2025/vwo/vakken/exacte-vakken/biologie-vwo
[30] Examenblad Scheikunde 2025 (accessed 23rd May 2025) https://www.examenblad.nl/2025/vwo/vakken/exacte-vakken/scheikunde-vwo
[31] Examenblad Natuurkunde 2025 (accessed 23rd May 2025) https://www.examenblad.nl/2025/vwo/vakken/exacte-vakken/natuurkunde-vwo
[32] Examenblad Wiskunde B 2025 (accessed 23rd May 2025) https://www.examenblad.nl/2025/vwo/vakken/exacte-vakken/wiskunde-b-vwo
[33] A. Singh, *Int. J. Adv. Acad. Stud.* **2023**, *5*, 30–32. https://doi.org/10.33545/27068919.2023.v5.i9a.1049