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Co-Creating Durable Skills Education: A Case Study of The Collaborative Science for Biomedical Breakthroughs Minor

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ABSTRACT

As current challenges become more complex, bringing together people from different backgrounds to solve multifaceted problems has become crucial in the STEM field. There is growing recognition of the need to explicitly teach students the skills necessary to conduct inter- and transdisciplinary science, including communication, collaboration, reflection, and understanding of the research process. This set of skills is complex and requires acquiring knowledge and practice and changing attitudes. Moreover, these processes also require the cultivation of emotional skills, which are often neglected in the STEM field, especially in project-based learning programs that primarily emphasize technical expertise. As educators, we recognize our need to develop these competencies as well. This case study reports on the co-creation journey of an education program designed to teach collaboration with a strong emotional intelligence component in biomedical research to bachelor's students while providing them with a project to practice. This program also provides an environment for scientists, PhD students, and us as an education design team to improve our skills. We report on what we have done and learned from each other and our students in 360º education, including the program design process evaluation, which tends to be overlooked in the development process of such educational programs.

Keywords: Inter-and transdisciplinary education, durable skills, STEM, Co-creation

INTRODUCTION

As current challenges become more complex, bringing together people from various backgrounds to solve multifaceted problems has become increasingly crucial (Harris et al., 2010). Transdisciplinary research provides a means to address complex problems by bringing together multiple interests, worldviews, knowledge types, and ethical perspectives (Kalmár & Stenfert 2020; Kalmar et al., 2022). It is fundamentally a collaborative activity in which learning occurs not just within one person but also between team members (McGregor 2017). However, this is not a self-explanatory activity, and paying explicit attention to teaching collaborative problem-solving capabilities is often lacking.

During the COVID-19 lockdown in the spring of 2020, we, an education team from TU Delft and the Erasmus Medical Center, organized an open interdisciplinary research project on the topic of COVID-19, called the Corona Research Super Project (Sommers et al., 2020). The project included students from any level (1st year BSc to PhD) and any discipline (architecture to nanobiology) who wanted to contribute to learning about the virus and various aspects of the outbreak. The feedback received indicated that students and supervisors enjoyed the collaborative research experience but wished to learn more skills. This indicated a need in our students and in the work field to have an opportunity to explicitly learn several durable and emotional intelligence skills required to conduct meaningful collaborative research in a professional environment (Chinoy et al., 2022; Furner et al., 2022; Kopparla & Saini, 2022; Huang & Lajoie 2023).

The literature has indicated the need to explicitly teach students the skills necessary to conduct inter- and transdisciplinary research, especially in Science, Technology, Engineering and Mathematics (STEM) fields (Amelink et al., 2024). There is an increasing emphasis on educating responsible scientists and engineers who can develop innovations not only for society but also with society, considering the ethical, economic, and environmental impacts of their technical developments. Complex problems often require systemic transitions, which can cause changes in the power distribution within stakeholder groups, resulting in frictions of interests (Kalmar et al. 2022). Equipping STEM students with skills that extend beyond technical knowledge prepares them to work on these challenges responsibly after graduation (Gibbons 1997; Fisher et al. 2001; Park et al. 2010). Such skills include critical thinking, problem-framing, and -solving, communication, and adaptability, often referred to as durable skills (Minerva Project: Teaching Durable Skills Insights 2023). These competencies are more complex and broader than technical skills – they require changing attitudes and acquiring knowledge and practice. Furthermore, we use the disciplinary categorization of Klein, by which *"interdisciplinarity bridges and integrates existing disciplinary approaches with their respective languages, transdisciplinarity transcends and even transgresses them*." (Klein 2023), although we are aware that a stricter definition of transdisciplinary includes the engagement of non-academic, societal stakeholders as well (Kalmár & Stenfert 2020).

There are multiple ways to prepare students in higher education to be able to work and research in inter- and transdisciplinary projects. Educators can include separate, non-related activities in courses and educational programs facilitating the development of such skills, or they can set up inter- and transdisciplinary educational programs, during which students can experience the challenges and the added values of such integrative and collaborative learning with non-academic partners. Although the first option (integrating educational materials and methods into courses to teach these skills) is already challenging, setting up inter- and transdisciplinary education forms is said to be a complex problem in, and of, itself (McGregor 2017).

Various innovative education initiatives such as transformative, inquiry-based, and project-based learning have been designed to help students gain the necessary skills (Klein 1994). Project-based learning is a teaching method in which a case or challenge serves to organize and drive activities, typically with small groups of students working toward a final product to address the challenge (Krajcik & Blumenfeld 2006). In contrast to the traditional learning method of first acquiring knowledge to solve defined problems, project-based learning starts with a real-life problem and defines the knowledge required to solve it. This type of learning supports students' curiosity and helps maintain high intrinsic motivation (Helle et al., 2006; Amelink et al., 2024). By discussing challenges and working together on the final product, students can learn from each other and experience collaborative learning (McGregor 2017).

Project-based learning facilitates the development of various durable skills such as higher-level thinking, critical thinking, communication, project and self-management, leadership, decision-making, and conflict management (Laal & Laal 2012). These skills overlap with the crucial soft skills that executives search for in their employees, such as communication, interpersonal skills, flexibility (tolerance of uncertainty), responsibility, teamwork, and collaboration (Robles 2012; Pelosse 2022; Sultan et al., 2025). For a successful career, students must master technical knowledge and hands-on experience, labeled as hard skills, as well as a broad set of competencies that enable them to engage effectively in a work environment, reach their goals, and collaborate with other professionals (Prada et al., 2022).

Importantly, a certain level of social-emotional skills, such as empathy, self-control, responsibility, and emotional presence, is essential for collaborative learning (Tan & Jung 2024). Education and support for the development of these emotional skills are often overlooked in the STEM field, particularly in project-based learning programs that focus on technical skills (Elmi 2020; Ayeni et al., 2024). To foster collaboration, students need to engage with their own emotions and those of their peers, enabling them to better navigate group dynamics, handle conflicts, and communicate effectively. Such a lack of competencies can easily break a team and lead to negative outcomes in student learning (Huang & Lajoie 2023). As it is critical for students to develop these competencies (Chinoy et al., 2022), it should not be left to chance that they acquire these through project-based learning. Specific environments and instruction are required to support collaborative learning and the development of durable skills (Dillenbourg 1999).

To develop these skills, educators bring their experience into creating education; however, students' experiences and their participation in this process are critical to developing a truly effective program. Moreover, because of the inclusion of durable skills involved in the science process, the experiences of scientists and PhD students, both in what they wished they had learned in their education and what they need at their current career stage in a collaborative and transdisciplinary setting, are critical. A co-creation approach, or the so-called 360º model for the development of such a transdisciplinary educational framework, requires the participation of educators, scientists, PhD students, students from a given education program and societal stakeholders (Cook-Sather et al., 2014; Mercer-Mapstone et al., 2017; Bovill 2020; Kasnakoğlu & Mercan 2022).

This case study paper reports on our journey of co-creating a new minor, the Collaborative Science for Biomedical Breakthroughs (CSBB), designed to teach durable skills in biomedical research with a strong emphasis on emotional intelligence and reflection to bachelor students from different disciplines by providing them with a real-life biomedical project from the Convergence project (https://convergence.nl/), a transdisciplinary research project between the Erasmus MC, the Erasmus University Rotterdam, and the Technical University of Delft. In addition to teaching bachelor students, this minor represents a learning community providing teachers, scientists, and PhD students with means to develop their skills in collaborative research. This paper explains the design process and the framework for skill development encompassing supervisors, coaches, teachers, an online open-source textbook, and four different threads revolving around research skills, reflection, communication, and collaboration, with a very important component of emotional intelligence since this is generally overlooked in the STEM field. Although the design team's experiences during the development process of transdisciplinary and/or project-based courses is a crucial factor in their set-up, and because of the limited attention to this aspect in the literature, we also present here an evaluation of how the design team experienced it. Finally, we reflect on the framework and provide advice to educators wanting to replicate this structure of teaching collaborative research skills in a transdisciplinary setting with a strong aspect of emotional intelligence based on the challenges we faced when setting up and teaching such a program.

The choice for a descriptive case study approach and accompanying reflection is informed by the strong context-dependence of our co-creation journey. Case studies are favored research approaches for analysing complex social and learning phenomena, where the distinction between the context and the phenomena is not always clear cut (Yin 1994; Yin 2009). Although there are many caveats to the generalizability of conclusions from particular case studies, Stake contends that case studies provide exemplars from which a great deal can be learned (Stake 2005; Flyvbjerg 2006). It is in this sense that we explore and report upon our co-creation journey, seeking to inspire and advise other transdisciplinary educators.

Education design

The education design process began with two people (director and coordinator) with a vision based on the Corona Research Super Project (Sommers et al., 2020) to bring together an initial team with supervisors, students, teachers, and education advisors. Our goal was to develop a transdisciplinary and challenge-based education program in collaboration with the Convergence project that allows third-year BSc students from various universities and BSc programs to develop transdisciplinary research competencies. We chose to create a minor because these educational programs are more flexible and naturally combine students from different studies. Another advantage is that these are often smaller programs with lower enrolment, which is more manageable for the type of intense collaboration skills we aimed to develop.

In the Dutch university education system, a university bachelor's degree is a three-year program (180 ECs) that consists of two years of coursework often with no student choice. Year 3 includes of a "minor" which can be 15 or 30 EC depending on the program or university and usually happens in the first one or two quarters of the year. The year includes more coursework, often culminating with a bachelor end project. Minors are an opportunity for students to explore other topics and often students follow them at universities outside their own. Usually minors are smaller and focused, enrollment can be anywhere from 10-150. For the CSBB minor our enrollment has been 15-18 students with a goal to grow to a maximum of 50.

When creating a transdisciplinary challenge-based program such as this, it is crucial to develop a strong shared vision of hopes and aspirations for students. We wanted to help students develop and practice the key durable skills required for research environments, or almost any work environment so they could be effective collaborative researchers skilled in communicating with reflective and emotionally intelligent habits (process). However, practicing durable skills without content is neither engaging nor enjoyable. To address this, we have students experience jumping into an unknown topic and, using the knowledge and skills they are learning, develop a research question and project: the joys, uncertainty, and frustrations of developing a research project on a topic they know little about (content). Just as importantly, we wanted to learn from the students what they needed to develop these skills.

We developed four broad learning goals that focused primarily on durable skills rather than content **Table 1**. While these are durable skills that stay with a person (endure) and are applicable in job situations that involve learning and working with other people, we included some that are especially relevant to the biomedical research environment. These skills are in alignment with the skills outlined in the European Competence Framework for Researchers (https://research-and-innovation.ec.europa.eu/system/files/2023-04/ec_rtd_research-competence-presentation.pdf). When developing these learning goals, we realized that they were not just for the students, but also for all participants: teachers, students, and coaches.

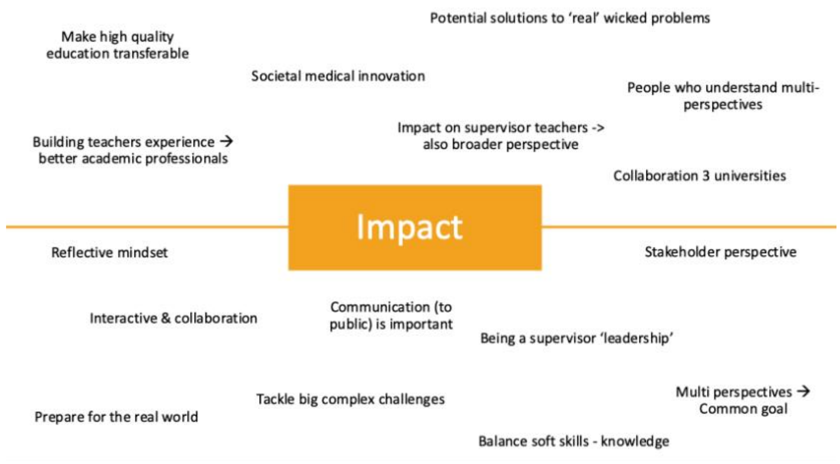
Table 1. Four learning objectives of the minor, reflecting the four key durable skills defined in the program.

LO1. After finishing this minor, you will be able to communicate research clearly to different audiences in oral, written, and visual formats.
LO2. You are able to collaborate with peers, other groups, and stakeholders from different disciplines and backgrounds to address challenging questions.
LO3. You are able to perform research and develop strategies for understanding a problem and designing inquiries.
LO4. You are able to reflect on what is known, what is unknown, and what you do not know, and provide and utilize feedback.

This created a dynamic learning environment with a strong growth mindset for all and modeled this for students. The design process took approximately 18 months from kicking off to class. It was divided into two phases: a broad overview design to define impact and develop learning objectives, assessments, and course content (1); and implementation, including refining learning objectives and assessments (2).

Phase 1

Initially, we collaborated with an educational advisory team attached to the Erasmus University Rotterdam, Risbo, with expertise in education design. We used a framework of constructive alignment (Biggs 1996), namely, aligning the learning objectives of the minor with assessments and teaching and learning activities and defining what is needed to be explicitly taught (process) and what students could teach themselves and each other (content). We used the principles of the Carpe Diem design method (Salmon & Wright 2014). The team consisted not only of students and experienced teachers but also specialists on specific topics and transdisciplinary design evaluators. We also collaborated with a private company, external to the university, to develop workshops and lectures in the program, bringing this collaboration to a truly transdisciplinary level (Kalmár & Stenfert 2020). Precisely because of this diversity in backgrounds, we generated great ideas for the program design. Because the students participated equally in these sessions, the discussions immediately included the perspectives of the students for whom this minor was developed. As shown in **Figure** 1, the impact of the minor program was designed from the beginning for broader implications than individual student learning goals, creating a learning community for teachers and supervisors.



Alt Text: An infographic with Impact written in the middle with different ideas related to the impact of the minor, such as building teachers' experience to create better academic professionals and potential solutions to real wicked problems. By the end of this design phase, we had a clear vision, learning goals, and an outline of the components of the minor.

Figure 1. Infographic of the desired impact of the minor.

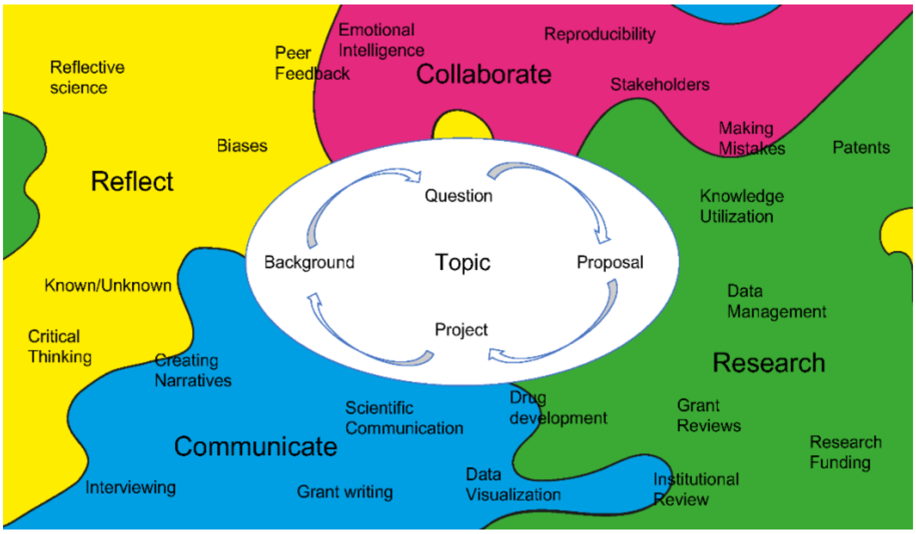
The design sessions were guided by educational advisors, bringing outside expertise to the topic at hand and using different techniques to brainstorm and create new ideas on the overall goal and vision, learning objectives, target group description, design principles of the minor, designing assessments and grading, and storyboarding (choosing the right resources and teaching and learning activities in line with objectives and assessments).

Phase 2

In this phase, our design team recruited expert thread leaders and brought in new students. Regular design meetings helped us spend time together, which was key to improving our ideas and including multiple perspectives. This phase transformed the program outline, created in the previous phase, into a coherent narrative arc. This included defining the exact order of skills needed and designing an onboarding workshop for supervisors and coaches (see the Supervisors and coaches' section) so that they understood the vision and principles we were working toward and had the skills to guide the students. During this phase, several opportunities arose that we took advantage of; for example, a new system for doing online interactive textbooks (Jupyter Notebooks) allowed us to expand and open our course manual. During and after this design phase, a series of surveys on the perceptions of each team member on the transdisciplinary design process were conducted to track our learning (see the Evaluation and analysis section).

Framework for skill development

The CSBB minor framework creates a scaffolding of competencies in communication, collaboration, research, and reflection around a research project, giving competencies context and relevance **Figure 2.** The research context is a type of sandbox for students to build in while developing their competencies. It combines project-based and transdisciplinary learning and explicit durable skill development.



Alt Text: An illustration showing in the middle an ellipse representing the cycle of research between background, question, proposal, and project and within this cycle, the topic of the project. Around the ellipse are the four durable skill areas, research, reflection, collaboration, and communication, with different skills we deemed necessary for conducting research.

Figure 2. Building blocks of the minor: the research context as a challenge in the core, with the four skill domains around it.

Because of the interconnectedness of the skill development and the autonomy of students to choose their research content and plan, we designed the minor as two large blocks (quarters) of 10 weeks full time (15 European Credit Transfer and Accumulation System credits each). In Q1, students develop a specific research question related to the chosen subtopic while performing an extensive literature review of the background, ensuring that they spend sufficient time defining a research plan to answer the question in a structured manner (Fischbach 2024). In Q2, students perform their research project by analyzing available datasets, generating new data, and performing experiments. In the meantime, during both Q1 and Q2, they build their understanding of the scientific research process and develop the durable skills they would need in a real-world situation of conducting such a project in a socially responsible manner.

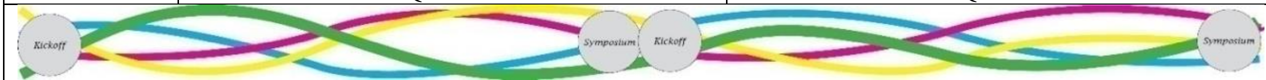
To make the research project relevant and have a mechanism for feeding ideas into research, in 2023–2024, we partnered with the Integrative Neuromedicine Flagship (https://convergence.nl/flagship-integrative-neuromedicine/) and Janssen Nederland, a non-academic partner.

The Flagship and the company provided complex subtopics for study, such as aging, Alzheimer's early biomarker detection, imaging, and depression. Each group of 4–6 students chose one subtopic to develop the research questions and plan. They were supervised by an established scientist and a PhD student (see the section below about supervisors and coaches). In 2024–2025, we partnered with iCell (https://www.erasmusmc.nl/en/research/projects/icell#8993263f-b6af-405f-a5b8-1e5ca13b62c6) for a different research focus.

While students have the autonomy to select a research subtopic and create a research project relevant and interesting to them, we provide a regular structure of lectures, workshops, and seminars to help them develop durable skills. Most weeks consist of a discussion of theories and a practical workshop on related skills, such as crafting a narrative combined with how to write an abstract. On Fridays, all students, supervisors, and coaches come together to discuss group projects, questions that arise during the week (content), and/or durable skills of the week (process). Friday discussions also focus on reflection and emotional skill development, with a place for troubleshooting and mutual aid.

At the end of Q1 and Q2, students have a set of deliverables accompanied by a set of grading rubrics for the different learning goals associated with them **Table 2**. The rubrics can be found in our online textbook (https://interactivetextbooks.citg.tudelft.nl/csbb-textbook/intro.html) and are focused on the process rather than the content/topic.

Table 2. Deliverables for Q1 and Q2 used for assessments.

	Quarter 1	Quarter 2
		
Group	• Short grant application modeled on the Dutch National Science Organisation (NWO-XS style; https://www.nwo.nl/en/calls/open-competition-domain-science-xs-package-24-1) consisting of two pages, including all application components and budget • Poster presentation at a regional scientific meeting where members of the Flagship also participated, in front of their peers, PhD students, and principal investigators, as they might at a real scientific meeting as a PhD student	• Scientific paper including a cover letter to the journal of their choice (group assignment), formal peer review, and subsequent rebuttal letter. Actual submission did not happen. The students understood the stages of writing a scientific paper. • 20-minute research talk at a general public symposium. Students presented their results.
	Quarter 1	Quarter 2
Individual	• Critical thinking portfolio linked to each week's topic • Participation in Friday symposiums • Oral exam	• Critical thinking portfolio linked to each week's topic • Participation in Friday symposiums • Oral exam

Alt Text: A simple sketch of the organizational structure of the program, with the team of students on top of supervisors and coaches and around these three, the four different thread leaders. Surrounding this distribution are the program director and coordinator.

Supervisors and coaches

The student teams are each assigned one or two supervisors (principal investigators or senior post-docs from the given Flagship) and coaches (PhD students from the participating institutions) **Figure 3**. Based on our number of students (15-18) and the number of groups (4-6 students/group), we recruit around 5-6 supervisors and 5-7 coaches per academic year. This also means that supervisors and coaches can co-supervise a single group of students. Each supervisor and coach spend in this minor around 1.5-2h and 2-3h/week, respectively. Several supervisory teams are cross-institutional, containing multiple supervisors and coaches from various departments or universities, promoting collaboration and fostering innovative ideas and connections at the supervisory level.

While coaches closely supervise and assist with daily logistics as needed, supervisors focus on advising on the research process. Coaches lower the supervision threshold for students, help them manage their project plan, perform weekly tasks, and have an early eye on conflicts. On the other hand, supervisors guide the students in formulating research questions, designing projects, and the grant and final paper writing process. Indeed, supervisors may not be experts in the topics their groups are researching but may provide overarching expertise in the process of doing research, ensuring that the students remain responsible for the content of their research. Students are graded on the process and how they write and discuss their ideas, not on the quality of the scientific idea, which ensures homogenous grading. Supervisors and coaches can also learn in this process. They receive supportive guidance from the teaching team on supervising transdisciplinary student teams with all conflicts that can occur within them. They also reflect more on the elements of scientific processes.

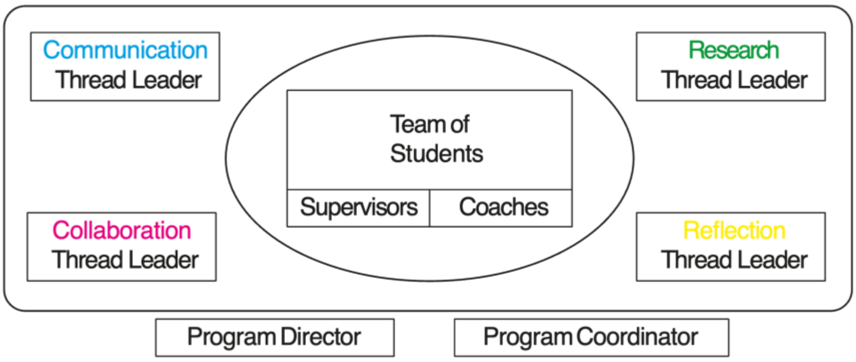


Figure 3. Organizational structure of the program.

Textbook

To connect many distinct ideas and durable skills in this program and because considerable learning is self-directed by students coached by supervisors and coaches, we designed a strong framework as a navigational aid to guide their journey **Figure 4**. The minor was built to be transferable to different research topics and open to anyone. For this purpose, we created an open-source interactive textbook using the Markdown language in Jupyter Notebook. This allows easy navigation and updating as we improve and update our materials. Its contributors included the development team, supervisors, teachers of individual workshops, and student-teaching assistants. The minor program is organized into thematic weeks, where each week became a book chapter. Each chapter includes topics and learning goals for the week, including why we think these are important and how they fit into the big picture. In addition, it includes discussion questions, benchmarks regarding where they should be on their research projects, and weekly assignments. The book does not replace student-teacher interaction; it is not a mere substitution for the lecture/workshop content, but it contains a small snapshot of what will be taught in each session. Feedback from students, supervisors, and others who have used it is highly positive. When building a collaborative program with many participants, it is critical to have a shared vision document to help guide and maintain focus. The textbook serves this purpose. It includes our expectations of ourselves and students and helps everyone stay organized.

Alt Text: A sample textbook cartoon showing a river with the four different colors of the threads (green, yellow, pink, and blue) with different panels indicating the weeks and the activity that will happen during that week. The students are sailing in a white boat through the river, stopping at each week, while the coaches and supervisors sail on a different black boat, coaching them throughout their journey.

Figure 4. Sample textbook page Q1 week 1.

We envisioned the students going on a learning journey by boat, each week stopping at a certain point to learn a specific skill or background knowledge. The supervisors and coaches are on a tugboat beside them—not to tug at them but to guide them in the process. All four threads (see next section about Teaching durable skills) are represented with the four colored parallel stripes.

Teaching durable skills

The competencies taught were grouped into four threads—research, reflection, communication, and collaboration—braided around the central research topic. Each thread is headed by a thread leader, an expert in their field **Figure 4**. They are not taught in isolation, but as part of the entire research process. Each skill-related lecture and workshop is assigned to one of the four threads but contains parts of the other threads, ensuring deep intertwining among them. It can be difficult to distinguish the thread to which a skill belongs, and they often overlap. For instance, we assigned grant writing to communication, but understanding the process of submitting grants requires elements of the other threads; making a budget is a research skill, doing a project with someone else is collaboration, and most grants require a reflection section on how it fits into society.

Research

The research thread of the minor focuses on teaching research-related skills and understanding the processes and requirements of biomedical research projects and laboratories. The content of this thread was determined in large part by asking PhD students and post-docs what they wished someone had taught them, instead of just having to figure it out.

The thread is organized into two parts. In Q1, students learn to formulate research questions and receive lectures and workshops on problem definition, grant applications, stakeholders, the research ecosystem, knowledge utilization, and intellectual property. Students are also provided with practical guidance on using tools to frame their research questions and create research proposals (Sudheesh et al., 2016). This guidance includes a literature search and data mining. Early feedback on the initial questions is provided in week 2. Both peer and instructor feedback is integral to teaching students how to refine their questions on a particular subject. This is done in a real-world context. For example, the proposal that they write as a Q1 deliverable is in the format and meets the requirements of a standard Dutch NWO-XS grant submission. They also need to deliver a poster presentation at the end of Q1, which must meet the requirements of a local scientific meeting. In 2023–2024, students presented their posters at the 5th BEI Meeting on Neuroscience and Engineering, along with other PhD students and post-docs.

In Q2, students develop answers to the research questions formulated in Q1. Experts in lab budgets, lab safety, ethics, data analysis, visualization, and sharing give lectures and workshops about their field of work. At Q2's end, students write a short communication paper, peer-review each other's work, present their data at a seminar, and engage in discussions with external stakeholders. They are required to decide to which journal to submit the paper and write the paper to meet those requirements, a submission cover letter, and a rebuttal to the peer review to give them an experiential understanding of the actual process of paper publication.

The knowledge and skills in the research thread include information literacy skills (searching, finding, and critically assessing scientific literature), formulating relevant research questions, impact analysis (related safety, ethics, environmental, and social aspects) of the proposed research, proposal writing, and understanding of the research environment of a working biomedical research lab (Danowitz et al., 2016; Khalaf & Alshammari 2023).

Students have autonomy in choosing their topics of interest, formulating research questions, and shaping research projects, which has a high potential to increase their motivation. Furthermore, they can interact with principal investigators, post-docs, and PhD researchers in a safe environment within a learning community, shaping their identities, boosting their confidence, and helping their personal development. With this understanding, they are better prepared to enter research laboratories as PhD students.

Students choose research contexts from around 8–10 subtopics aligned with the minor theme: Integrative Neuromedicine in 2023–2024, such as esketamine treatment for depression and early detection of Alzheimer's biomarkers, or iCell in 2024–2025.

Reflection

While planning and performing a research project requires cognitive skills, metacognitive skills are necessary to understand how the tasks proceeded and how to learn from them (Hartman 2001). Experienced researchers often implicitly connect cognitive and metacognitive perspectives, making it challenging for students to develop an understanding of the underlying assumptions and rationales. In our case, we emphasize metacognition throughout the program in all the threads, with the students but also with the supervisors and coaches, in helping them explicitly separate the perspectives and deepen awareness. Metacognitive skills are usually defined as skills related to knowledge of cognition (related to what students know about their cognition) and regulation of cognition (students' activities to control their cognition, such as planning, monitoring, and evaluating)(Hartman 2001).

The reflection thread aims to train three specific metacognition-related skill sets: Aim 1) to uncover students' and the scientific field's implicit assumptions and rationales (which can be defined as knowledge of cognition); Aim 2) to self-reflect on the individual progress of scientific research within a student team and then broadly reflect on the progress of scientific fields; and Aim 3) to develop skills related to the emotional aspect of collaborative interactions in science (monitoring and evaluating emotions)(Ayeni et al., 2024). We address Aim 1 through lectures, workshops, and student-teacher conversations on sustainability choices, implicit biases, failures, and problem-solving techniques in academic research. These conversations encourage students to question and justify their assumptions and rationales regarding research handling, progress, and value. Aim 2 focuses on enhancing self-reflection to help students deepen their understanding of how they learn and enable self-steering learning strategies, as well as how science learns and develops research strategies. Students deliver weekly critical reflections covering topics such as individual oral preparation strategies, individual well-being, and progress struggles and broader questions such as how we think about applied knowledge versus knowledge for the sake of knowledge. These reflections help students plan, monitor, and evaluate their learning, revealing their strengths and weaknesses in learning and thinking, like scientists do (https://educationendowmentfoundation.org.uk/education-evidence/guidance-reports/metacognition).

Friday symposia provide an important and critical moment for Aim 3, where students reflect on and practice the emotional aspect of their interactions with other students from different disciplines, which is lacking in the STEM field (Ayeni et al., 2024). The Friday symposia are led by the program director and/or coordinator, with at least one coach and one supervisor also in attendance. They are done in a socratic manner of asking questions. The discussions are based on issues we see arising amongst the students, the weekly reflection assignment and textbook discussion questions. They are very responsive to where the groups are. Discussion topics have included: getting discouraged when a project is not working, noticing how that affects your work and what different people do in those situations; identifying when there is a problem in your collaboration group, emotional intelligence skills you can use (trust, vulnerability, curiosity) to address those; how to do consensus bargaining to make a plan for the whole group. We also use those sessions as a lab meeting to problem solve or brainstorm: where to go for lab resources; workshop paper titles. And lastly, we have discussed big questions related to research: applied knowledge vs knowledge for knowledge's sake and how that relates to research funding; criteria journals should use for deciding whether to publish research articles. Together these topics greatly increase the students (and everyone else's) ability to have thoughtful, emotional conversations about doing scientific research.

Communication

For students to learn how to communicate their research clearly to different audiences and settings (oral, written, and visual), the communication thread of the minor focuses on various communication skills throughout the program. The cornerstone for developing a communication thread is the theory of the rhetorical situation. Originally developed by Bitzer (Bitzer 1968), this model allows students to analyze any communicative situation based on essential components such as the author (writer/speaker), audience, message, and context (Threadgill & Paulson 2018; Kjeldsen et al., 2019). Accordingly, students can critically analyze the characteristics and effects of examples in various communication genres (Wang et al., 2023) and design preparation strategies for minor deliverables aimed at different audiences.

Using the rhetorical situation as a point of departure, workshops on communication skills aim to connect students' research processes throughout their minor. In Q1, students work on developing critical reading skills to help them review the literature and develop a research question using a Scientific Argumentation Model (Lacum et al., 2016). Furthermore, they learn about interviewing and listening skills, how to create narratives, how to use visuals in their communication (e.g., for poster presentations), and how to write and present their research topic (e.g., a research proposal and a poster presentation at a research symposium). Constructive peer feedback forms another key element in these communication workshops, in which project groups critically review their own work and those of other groups. The presentation workshops also address stage fright, adapting to students' individual needs. In Q2, writing and presentation skills are strengthened, revisited, and applied to other deliverables, such as research papers and presentations to stakeholders.

Collaboration

Collaborative learning teams in a project-based course or curriculum, consisting of students from multiple disciplines working together on an original and usable (ergo creative) outcome, often face challenges related to teamwork. Diversity in knowledge, perspectives, and workstyles contributes to creating innovative solutions but can cause conflicts and reduce team effectiveness. To support collaboration, we focused on six determinants of creative team performance while designing workshops and activities related to this thread (Kratzer & Mrożewski, 2021):

1) Social networks: The environment in which team members are embedded is a crucial factor in determining team effectiveness and creativity. Since the teams are formed of students from a wide range of educational programs (history, psychology, mechanical engineering, nanobiology, etc), activities such as topic-specific games and transdisciplinary workshops help build strong ties and transactive memories among team members and create team rules. Transdisciplinary workshops focus on making students aware of the differences between how they, as representatives of various disciplines, look at the same problem, what type of knowledge do they possess, and which ways of working do they prefer when confronted with a challenge. Through different activities, we also facilitate interactions between members of different teams. These activities focus on training skills such as perspective taking, empathic listening, information sharing, and getting along as teammates (Strom & Strom, 2011).

2) Leadership: Students take the Belbin test to identify preferred roles and are encouraged to try new roles, practicing skills needed for attending teamwork (Strom & Strom, 2011; Shaari et al., 2022) and leadership and project management skills (Sohmen, 2013; Steeves et al., 2025) within a safe environment.

3) Network structures: Diverse transdisciplinary teams are formed based on Belbin's roles, BSc disciplines, and gender. After a facilitated decision-making session, each team chooses a subtopic and is assigned to supervisors and coaches. The teams have a high level of autonomy and are self-managed, under the guidance of the supervisors and coaches.

4) Communication media: Face-to-face meetings and symposia facilitate effective communication, promoting attending teamwork sessions, active communication between team members and supervisors, information sharing, and getting along within and among teams.

5) Managing conflict: Teams create team contracts to discuss expectations and learning goals. Guided discussions on conflict cycles, emotional intelligence skills, and the emotional needs of collaboration help address issues. They are generally successful at resolving problems and furthering students' conflict-resolution skills.

6.) Creative culture: To spark creativity within teams, we provide them with a list of research areas with potential for challenging projects. Teams have the autonomy to choose subtopics, directions, and approaches for developing their projects. Risk-taking and idea generation are encouraged using the team's disciplinary diversity as an asset while welcoming various perspectives. We also explicitly work on modeling this process for our students, including openness to mistakes, changing when things are not working, and trying things.

Evaluation methods

We collected information from our design team throughout Phases 1 and 2 of the course design process regarding how the perceptions of the design team members changed before and during this design challenge. Information was collected according to the standards of the Human Research Ethics Committee of the Delft University of Technology, and informed consent was obtained from all participants. After collecting identifying information, we asked the same nine questions at two different time points (Survey 1 and 2) during the design process (Supplementary Tables 1 and 2). These questions revolved around the participants' expectations, contributions, and involvement in the CSBB design process, including the outcomes they aimed to achieve, their role, and their familiarity with specific elements. Additionally, they were invited to share insights on their learning experiences, what they hoped to learn or teach from each other, as well as their perspectives on the project's process and product quality. In addition, in the final survey conducted after the minor's completion (Survey 3), we asked the design team to reflect specifically on their overall learning and perceptions of the quality of the experience (Supplementary Tables 2 and 3). While 11 to 15 members of the design team replied to surveys 1 and 2, 7 members replied to survey 3 (see the next section about Lessons learned for the surveys analysis).

During the actual course, the design team evaluated the progress and adjusted the approach where necessary. Students communicated their feedback through several means such as personal communication, Friday symposia, an anonymous online feedback system, and official course surveys.

Lessons learned

During the course design

The surveys conducted before the start of the minor program (Surveys 1 and 2) revealed that our design team already recognized multiple types of knowledge and the wide diversity of people in the design team. The expertise of the respondents included (but was not limited to) neuroscience, bioinformatics, ethics, nanobiology, and education. In terms of their own involvement in this project, respondents recognized (Question 4) both the challenge of organizing "such a complex" educational track and the complexity of collaborating with people with different views and expertise.

The design team members generally wanted to learn (Question 5) how other fields approach their topics, the actual implementation of transdisciplinary in the projects, and more skills to help people work together and build frameworks.

Similarly, the team wanted others to acquire (Question 6) interpersonal skills and networking information but not substantive disciplinary information. For instance, they strived to learn how to communicate effectively, learn ways to collaborate well in the future, and how to best work together with this group of people. In effect, this means learning how to adapt how you work in a group and how the group itself works, as well as how to work with people from different fields and levels of work experience.

After the minor program ended, we evaluated the learning of the design team through a third survey. The team members believe that the minor equips students both for exploring biomedical science and working collaboratively in a transdisciplinary setting (Question 8), arguing that students now also understand why transdisciplinary is important.

The members of the design team formulated the challenges of transdisciplinarity collaboration in various ways: *"I've learned to be (more) flexible in uncertain situations and how to attune various ingredients of an education program (skills, knowledge, content, personal development, tutoring/guidance)—trying to find a good balance in a collaborative education design effort, and aiming to complement each other, rather than mainly focusing on my own expertise." (Participant 1)*

"I think the learning process is ongoing: I believe I have developed and progressed, but there are continuous points of attention and development." (Participant 5)

The design team members indicated they "learned a lot," mentioning soft skills such as teamwork and team dynamics. The respondents recognized that the design process was a transdisciplinary project in which all their voices were heard.

"It was a democratic process, including all stakeholders, and we learned from each other. In that sense, it was a real transdisciplinary project." (Participant 3)

"Spend time together. Invest in really discussing the ideas until you get to where you want them. Make sure your group has collaborative skills before you try to teach them." (Participant 1)

One respondent indicated the need for a better assessment framework for transdisciplinary student projects, including best practices for weighing processes versus products or teamwork versus individual grades. Overall, the opinion that design team members were highly satisfied with the quality of the minor program was common across different fields of expertise and shared by both staff and students.

Drawing on the evaluations of the design team members' experiences before and after the design process, the team adopted an open engagement process that respected individual inputs yet facilitated learning. Their learning experiences were less about knowledge transmission and more about developing the necessary collaborative skills for the complex task of designing a novel transdisciplinary minor program. The design team embraced the inherent messiness of transdisciplinary; in this sense, it experienced a learning process like that of the students for whom the minor was designed.

During and after the course

Based on student feedback, two issues that led to several structural changes were identified: student demotivation and our assumptions about students.

First, the students' challenge to remain motivated emerged throughout the project. The team responded to this issue by openly discussing motivational issues in class. Furthermore, the weekly progress- and process-oriented presentations that students delivered in the first few weeks in Friday symposia created excessive stress for them, and sometimes they did not have much to present. Moreover, students preferred more content during the sessions. Therefore, we changed the format of these sessions to discussions on both content- and process-related topics, which was highly appreciated. Based on feedback from 2023–2024, these sessions are now, in the 2024–2025 edition of the minor, more explicitly divided into discussions of emotional intelligence and durable skills at large and discussions about the science projects being worked on. Throughout the week, the student attendance decreased to 66%. In retrospect, students attributed this to having lectures, and some lectures and workshops' (perceived) lack of immediate relevance to the project. Students were eager to dive into their research projects without seeing the wider relevance of certain skills and topics (e.g., data management and animal research). In 2024–2025, we have included workshops to increase attention, interaction, and attendance. In the following years, we will evaluate if student demotivation is a persistent problem or cohort specific.

Second, several of our assumptions regarding students proved incorrect. We wrongly assumed that students would know or have some skills related to collaboration, and therefore, started to discuss the emotional intelligence aspect of collaboration in Friday symposia (Huang & Lajoie 2023). We also assumed that students would be more curious about the background and literature they needed and expected a certain level of autonomy. However, we shifted our approach halfway through the first edition of the minor by developing a clearer structure and planning of their project.

The first edition of this minor taught us that it is important to be flexible and change the course's layout while it is ongoing, leaving room for adaptation to that year's student cohort. A trusting relationship between the teaching team and students should be created; students should be provided with space to share the issues they face.

After the course, discussions with supervisors and coaches revealed that the program may have been (too) time-intensive due to the high supervisor/coach-to-student ratio. To alleviate their schedule, we are now reducing supervisors' and coaches' presence at Friday symposia. However, a high teacher-to-student ratio is inherent in both learning skills and project-based learning.

While the four global learning goals were achieved by the students at the end of the minor, some students anecdotally communicated to us several months afterwards how they realized in retrospect about the space and time that we provided them to practice the skills they were being taught. They also realized that these insights and collaborative skills were absent in their own BSc programs. They told us that they acquired different perspectives on collaboration.

Reflection on the framework

Performance of the Q1/Q2 structure

Based on the quality of the deliverables and feedback from the students and supervisory team, the two-quarter minor structure—building a transdisciplinary team and defining the research question in Q1, looking for answers in Q2—was successful. However, better alignment between Q1 and Q2 is required to enhance the overall learning experience. Expectations for Q2 could have been better managed during Q1, particularly regarding the practical work, level of independence, and interaction with a private company. Students should be encouraged to propose feasible projects rather than overly ambitious ones, as in Q1. To increase coherence, students could revisit the research questions at the end of Q2 or define the next set of logical questions if they were to continue the project.

The four threads

We believe that the presence of these four threads was a success. They covered the most important aspects of transdisciplinary teamwork in a research environment and were assigned equal importance. They also helped us organize the schedule of the minor, providing guidance to the lectures and workshops and allowing the delegation of organizational responsibilities to each thread leader.

Although students reported understanding that the minor comprised four threads, it was not always clear to them to which thread each lecture or workshop was related. Furthermore, the crosstalk between the four threads could have been better highlighted during classes to help students integrate their knowledge with the rest of the sessions and the bigger picture of the minor. Moreover, in retrospect, we found some overlap between sessions organized by different threads. Thus, alignment, collaboration, and communication between different thread leaders, coordinators, and directors are critical.

General conclusion and advice

Our journey of developing the CSBB minor was a transdisciplinary project, including thread leaders with various expertise in reflection, communication, collaboration, and research and bringing in the students' perspectives in the course design. We took transdisciplinary team learning seriously and monitored how the design team members experienced the process. The design process evaluations revealed that the team members valued each other's input and focused on creating a framework to teach these skills in a collaborative manner, as we expect the minor students to do. Reflecting on this, we consider our organic process as a strength that aligns with the 4I theory of change (Stehle & Peters-Burton 2019; Reinholz et al., 2021). We used the 4I cycle of intuiting, interpreting, integrating, and institutionalizing to employ all the expertise of our group to change how we approach teaching critical durable skills to students.

We learned from each other and our students (360º education), leading to valuable insights into setting up a transdisciplinary educational program to teach the skills necessary to perform biomedical research. Emotional intelligence is generally not taught or developed in STEM fields, which tend to focus on hard technical skills (Ayeni et al., 2024). As collaborative and especially transdisciplinary efforts require important communication and reflection skills, we included a strong component of emotional intelligence through deep reflective conversations at Friday symposia and weekly individual assignments. Humans are emotional, and conflicts arise if they cooperate on a project. Our experiences demonstrated that it is beneficial to create a space for discussing the emotional intelligence skills needed to address those conflicts rather than to ignore them and hope the students would figure it out. As with 360º learning, this minor also supported us in improving our skills in these areas and understanding what the students needed.

This structure could help other programs that use student-led, project-based transdisciplinary learning become more effective. The structure reflects and teaches the real process of conducting scientific research, including understanding what is needed for a grant application, stakeholders, rules, and regulations.

For people interested in developing a program like ours, we offer the following lessons:

- Find enthusiastic and passionate individuals excited about the project and willing to contribute while simultaneously being critical.
- Have a clear idea of your long-term goal for the students—what do you want them to be able to do in five years?
- Education team models for students how to create a collaborative environment by working together encourage everyone to learn from each other.
- Make and schedule time periodically to physically work together to ensure consistent progress—time together for discussing ideas is the key to improving development.
- Acknowledging and celebrating achievements and milestones helps maintain motivation and morale.
- Be prepared to discuss emotional skills with your students or have an alternate plan.

- Risk-taking can lead to success but also to failure. Say yes more often than no. Being supported in accepting and learning from failure allows for growth opportunities.
- Co-creating the minor with students and stakeholders such as teachers and the private sector is critical. Ensuring that all contributions are valued is crucial for team enthusiasm and participation.
- As with all new projects, being able to adapt allowed us to learn from our mistakes and change the program where needed before starting and while running it.

We believe that these guidelines will allow the design of a dynamic and effective transdisciplinary program that will benefit both students and the broader academic community. We realize this sort of education is time consuming and expensive in staff time. However, we have used our learning from the development process and the running of the minor to influence and improve other educational programs at both bachelor and master levels. It also provided a unique opportunity for supervisors and coaches to develop their durable skills which they can use in their own fields and with other collaborators. We are also now working on ways to further share and develop the structures we have created with other like-minded and challenge-based minors within the Erasmus MC and TU Delft.

This paper describes a case study of the development and implementation of an educational framework for teaching collaborative research skills to students in a transdisciplinary milieu, while providing them with tools to improve their emotional intelligence. While the generalizability of a particular case study is limited, it can serve as an exemplar from which to learn. Here, we present an evaluation of the design process as a key element for learning and inspiration to educators. However, a critical aspect yet to be investigated is the evaluation of students' learning processes by comparing their durable skills before and after participating in this minor program.

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Author contribution

All authors contributed equally to this study. J.C. and H.M-B are co-founders and, respectively, coordinator and director of the CSBB minor. F.d'H. and J.S. designed, executed, analysed, and reported the design process evaluation. É.K., D.M., H.G., and M.W. are the leaders of the collaboration, research, reflection, and communication threads, respectively. J.M. is an educational advisor at Risbo.

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