# Yes, we can: Empowering 21st century skills in a large introductory classroom through project-based learning

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## Abstract

Fostering '21st Century Skills' is becoming increasingly important in view of the rapidly changing world, with transferable competencies such as critical thinking, creativity, collaboration, and communication being crucial to succeed in work and society. Adapting university teaching to these requirements necessitates the development of appropriate curricula, courses, and teaching materials, as well as examinations that can adequately measure these competencies.

Various teaching methods are suited to convey transferable competencies, in particular student-centred methods like project-based learning (PBL), where learners work collaboratively on authentic problems. Many studies demonstrated that PBL improves understanding, team performance, motivation, and critical thinking, in contrast to conventional teaching formats where students are exposed to the material more passively with few opportunities to actively apply concepts and question them critically. The flipped classroom model can also contribute to fostering '21st Century Skills' as shifting knowledge transfer to self-study creates space in courses for activities that train social and personal skills through discussions, group work, or PBL.

Promoting transferable skills is especially challenging in bachelor programs where courses are usually attended by many students with heterogeneous background knowledge, posing major challenges for lecture design. Thus, traditional, teacher-centred methods are often the format of choice. Here, we describe the development of a flipped classroom with a particular focus on project-based activities training social and personal skills for a large introductory biology lecture. By transferring part of the knowledge acquisition to the self-study phase, in-class sessions became free for project-based group work where students design experiments to study the genetic basis of diseases. At the end of the course, the groups present their projects in a poster session to their peers, the lecturers, and experts. Besides applying the knowledge acquired in the course, the group projects allow students to work on 'real-world problems' relevant to their field of study. Tutors (student teaching assistants) support students in their projects by providing feedback, clarifying questions, and evaluating the final project outcomes. The interdisciplinary nature of the project promotes problem-solving skills and critical thinking, while the didactic setting allows students to train their social competencies (cooperation & teamwork). Importantly, the group phase also impacts the skills development of the tutors, as they can expand their skills in the social and personal areas as well.

Implementing PBL to promote 21st Century Skills' in large, heterogenous classes represents several challenges including infrastructural constraints, organizational complexity, and student motivation. This paper describes how a flipped classroom approach can support the development of competencies by PBL and suggests solutions to address challenges associated with this teaching format. Our analysis of student feedback collected over multiple years indicates that the project-based approach is effective in key aspects, such as group productivity, student-tutor interaction, and student motivation, and suggests that for certain student groups, fostering a stronger sense of project relatedness remains an area for future improvement.

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# 1. Introduction

## 1.1 What are 21st century skills?

In a fast-evolving work environment, personal and social skills are essential for individuals to effectively apply their specialized competencies at work and in society. These abilities, which are often referred to as transversal skills or '21st Century Skills', are traditionally summarized as the '4Cs' (critical thinking, creativity, collaboration, communication) and are more recently extended to include digital and technological literacy (Ananiadou & Claro, 2009). Although transversal skills are not a new concept of the 21st century, the term '21st Century Skills' is appropriate as it highlights the growing importance of these complex abilities in a world where rote memorization is declining, and cross-disciplinary skills are becoming more significant.

To ensure that graduates meet these requirements, university education must adapt. Implementing competency-based teaching requires developments at different levels. For example, '21st Century Skills' must be defined and organized into a coherent system (e.g., competency frameworks). Furthermore, curricula need to be developed or adapted to support the teaching of these skills, and suitable teaching strategies must be applied. Finally, assessments or evaluation frameworks should be developed to adequately measure and evaluate these complex skills (Geisinger, 2016).

Creating a detailed skills framework applicable for curriculum and course development requires identifying skills across cognitive, intrapersonal, interpersonal, and technical domains. In this context, it is important to differentiate between 'skills' (referring to practical abilities, e.g., technical skills) and 'competencies'. Competencies encompass a broad range of elements, including skills, attitudes, knowledge, and behaviour (Baartman & De Bruijn, 2011). While the term '21st Century Skills' might not fully capture the concept of competencies, it remains valuable for highlighting the increasing significance of complex abilities in a rapidly evolving world and the necessity of acquiring these competencies for success. Consequently, this article uses '21st Century Skills' and 'transversal skills/competencies' interchangeably.

## 1.2 How can 21st century skills be fostered in university settings?

Promoting transversal skills is gaining increasing importance in higher education. Surveys of companies and potential employers rate the technical skills of university graduates as very high, while transversal competencies are often less well developed (La Cara et al., 2023; Abela et al., 2020). This suggests that universities have not yet fully exploited their potential in developing transversal skills. Many universities are responding by implementing competency frameworks that serve as guides for both instructors and students in skills development. These systems help instructors to intentionally foster competencies and make the promotion of these skills visible to students. For students, competency frameworks are useful for reflecting on educational expectations and becoming aware of their own competency development (Baartman & De Bruijn, 2011).

At ETH Zurich, a key educational focus is on equipping students to become responsible, critical members of society. Thus, to raise awareness and promote holistic skill development with a particular focus on transversal skills, the ETH Competence Framework was developed. It includes 20 competencies in four areas (subject-specific, methodological, social, and personal competencies) and describes the knowledge, skills, and attitudes associated with each competency and serves as a common 'language' for instructors, students, and future employers (La Cara et al., 2023).

Applying competency frameworks to university study programmes requires the development of appropriate curricula, courses and teaching materials as well as examinations that can adequately promote and measure these competencies (Geisinger, 2016). Universities are challenged by the increasing demand for competency development and respond by creating course formats that foster these skills, leading to the establishment of standalone courses or projects designed to develop specific competencies (e.g., writing courses, interdisciplinary project work, etc.). However, the main challenge lies in adapting the existing curriculum to integrate the development of transversal skills within regular courses and established learning units. Several teaching methods are effective in training transversal skills, including student-centred approaches such as project-based education (PBE) or problem-based learning (PBL), where learners work collaboratively on real-world problems (Zhang L. & Ma Y., 2023; Wijnia et al., 2024). Both PBE and PBL emphasize group work, problem focus, and tutor guidance. Further, they both facilitate the application of knowledge to real-world contexts, increase motivation, engage students in complex tasks and foster self-directed learning and interpersonal skills. Additionally, they both share a commitment to interdisciplinarity, self-direction, and collaboration (Servant-Miklos, 2020). To differentiate between the two approaches, project-based education emphasizes the creation of a product as a solution to a problem that demonstrates student's understanding of the material. In contrast, problem-based learning prioritizes the process of acquiring new knowledge over the solution itself. Some argue that problem-based learning can be seen as a subset of project-based education, as solving defined problems is one of the methods used within project-based frameworks (Wijnia et al., 2024). Many studies have shown that project-based education can improve understanding, team performance, motivation and critical thinking in natural sciences and engineering curricula (Burks, 2022; Ralph, 2015; Kurt & Akoglu, 2023; Webster et al., 2022.; Zhang L. & Ma Y., 2023), while in conventional formats, students are exposed to the material more passively and have little opportunity to actively apply concepts and question them critically.

## 2. Project-based education in an introductory course with 350+ students

Although there is a growing demand to foster transversal skills in undergraduate programs, the reality in STEM disciplines often shows that traditional lecture-based formats remain the preferred choice, leaving little room for the development of '21st Century Skills.' Introductory courses are often attended by many students with diverse prior knowledge, which poses significant challenges on course design. However, many studies present ways to address these challenges by successfully implementing interactive formats (e.g., flipped classroom models, Deslauriers et al., 2011; Freeman, 2014) and demonstrating how these approaches can promote transversal skills (Väisänen & Hirsto, 2020).

Here, we describe the development and implementation of an introductory biology course based on a flipped classroom model that fosters transversal skills by learning through projects. By shifting the knowledge acquisition partly to self-study, we created space in the classroom for student-centred activities that train social (e.g., cooperation & teamwork) and personal skills (e.g., critical thinking) through project-based education. We also discuss the challenges associated with fostering transversal skills and present our approaches to tackling these challenges based on our learnings from seven years of implementing PBE. In summary, our approach illustrates how a project-based group phase helps Bachelor's students to tackle 'real-world interdisciplinary problems' that are relevant to their field of study with the help of course concepts in order to promote problem-solving skills, creative thinking, and collaboration.

### 2.1 Course structure and teaching activities

The course is an obligatory, first semester introductory biology lecture tailored to students studying health sciences and human medicine. It is composed of lectures, self-study modules, and project-based group work sessions (see Figure 1). The course is managed via the learning management system Moodle. During the asynchronous self-study phase, students primarily work individually on study materials specifically designed for the course (interactive lessons and quizzes). An online course forum is available for discussions. The knowledge gained through self-study is reinforced in the input lectures, which are supplemented with interactive elements such as clicker questions, think-pair-share activities, and concept mapping.

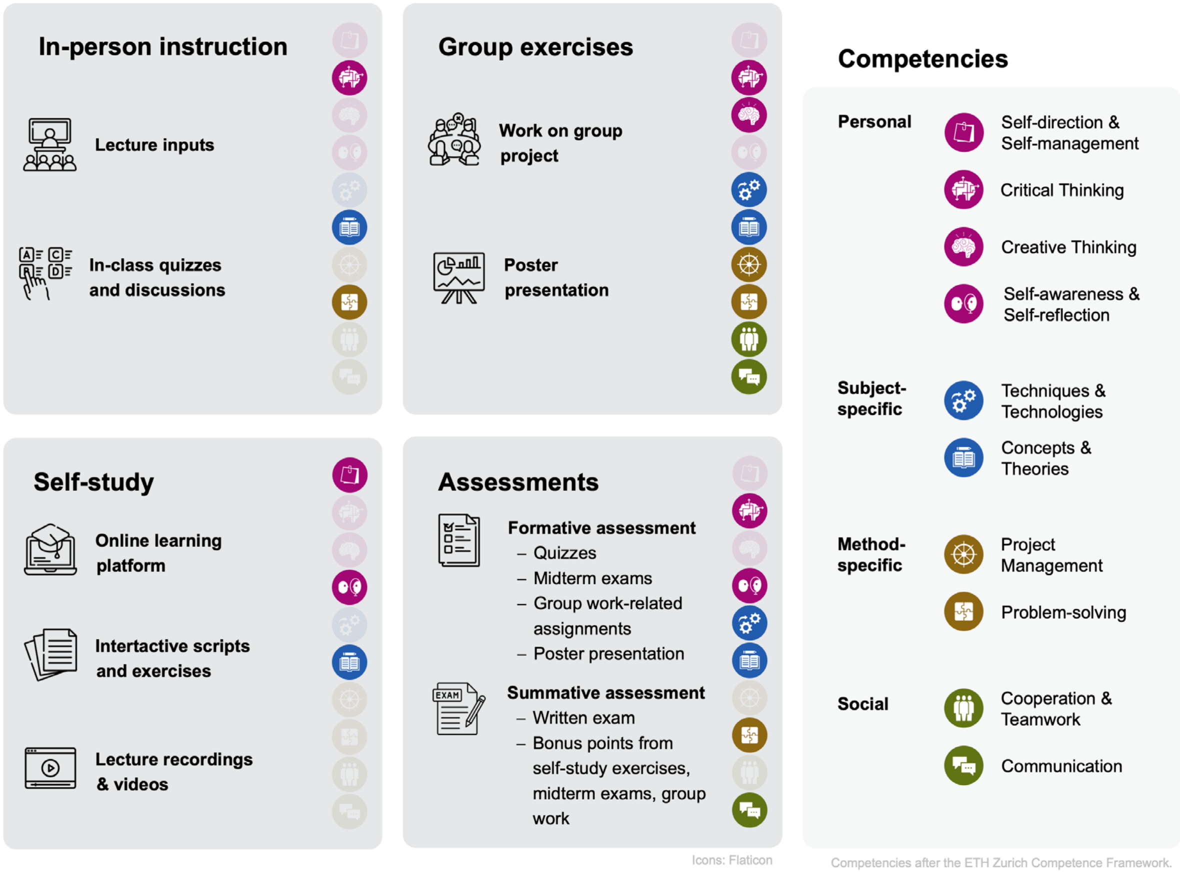


*Figure 1: Overview of course activities and transversal competencies fostered. 50% of the lecture time is dedicated to in-person instruction, 30% to self-study, and 20% to tutored group project work. Several formative assessments during the semester are awarded with bonus points that can increase the final course grade. Competencies trained are highlighted (ETH Competence framework: Copyright: ETH Zurich).*

In the project-based group phase, students work in teams of four on an experimental study to investigate the genetic basis underlying a disease, which they present as a poster in the last week of the semester (total number of teams on average: 90). While students can choose their teammates, the project (e.g., the disease) is allocated to each group for organizational matters (for example, to ensure that all projects are evenly distributed among the student teams). Besides applying the knowledge and techniques acquired in the course, the group projects allow students to work on 'real-world problems' relevant to their field of study. Through their work on the group project, students not only acquire method-specific competencies (e.g., problem-solving) but also social skills (collaboration & teamwork) and competencies in critical thinking, which is promoted by the interdisciplinary nature of the project. An overview over the group project phase is shown in Table 1.

Students from higher semesters act as tutors to coach the groups during their projects, meeting the groups every two weeks to discuss progress, clarify questions, provide feedback, and evaluate the final products and presentations. To exert their role, the tutors receive specific training and ongoing support throughout the semester from experienced tutors and a senior member of the teaching staff. The group phase also contributes to the competency development of the tutors, allowing them to strengthen their social skills like leadership and communication, as well as personal skills such as self-reflection.

| Milestones in the group project phase | Contents and expected deliverables | Evaluation criteria |
|---|---|---|
| Group contract design | Group contract addressing the following aspects:<br>- Communication (also in case of disagreement)<br>- Distribution of work | - Completeness regarding the two main criteria<br>- Timely submission<br>- Confirmation by all group members |
| Literature review | Independent literature review on disease characteristics and molecular mechanisms of the disease | None. |
| Information gathering | Collaborative disease profile design focusing on:<br>- Definition and clinical picture; onset of illness, life expectancy, and prevalence; therapeutic options<br>- Disease inheritance; genetic basis and molecular disease mechanism | - Accuracy of the contents<br>- Formal accuracy<br>- Proper bibliography and appropriate reporting of AI usage |
| Peer feedback I | Mutual feedback within the groups on individual disease profile sections. | - Completeness of feedback (positive aspects and suggestions for improvement)<br>- Constructiveness of feedback |
| Group work reflection I | Self-reflection feedback form to assess group work processes and personal learning outcomes; definition of a personal learning goal. | Marked as completed or incomplete.<br>Anonymized results were discussed with the teaching assistants in the following exercise class to address potential problems. |
| Experimental design | Collaborative design of an experiment consisting of consecutive and logically connected steps to approach the previously reviewed disease. | Accuracy of the contents. |
| Peer feedback II | Between-group presentation and student-led feedback session on the preliminary elaboration of the experimental design. | None. |
| Poster preparation | Collaborative preparation of a poster combining information from the disease profile and the experimental design. | - Formal aspects: grammar, referencing, AI-usage, appropriate title choice, deadlines, and layout<br>- Accuracy of the contents, described methods, and proposed next steps |
| Poster presentation and discussion | Student-led and teaching assistant-guided presentations of posters in a conference-like session. | Active participation through presenting, asking questions, and engaging in discussions. |
| Group work reflection II | Self-reflection feedback form to assess group collaboration (including possible intervention) and achievement of personal learning goals. | Marked as completed or incomplete. |

*Table 1: Overview of the group project phase.*

## 2.2 Competency development in the group phase

The transversal competencies developed in the course are fully integrated into the subject-specific context, making their application and refinement more meaningful for the students. For example, during the group work, students deepen their understanding of the methods discussed in the course through the planning of an experiment, while simultaneously acquiring skills like problem-solving, critical thinking, and collaboration & teamwork, which are essential for their future work in a research group, in a hospital, or in industry (Figure 2).

The group project tasks are formulated to represent ‘real-world scenarios’ that students may encounter later in their career. For example, in one case, students are asked to step into the role of a Master student seeking a fellowship to pursue a doctoral study on a specific disease in a lab. The group’s task is then to design an experimental study and present it at a conference in front of the fellowship committee to compete for the fellowship. The best poster presentations are then awarded with a price, symbolizing the fellowship.

The task of the group project is designed to foster problem-solving and critical thinking skills: by having to design an experimental study, students learn how to use resources and techniques to find possible solutions to a problem. By doing so, they need to evaluate different solutions and situations (e.g., experimental approaches) and choose the one they think is best suited to answer their research question. There is a specific emphasis in the group work on literature search and correct citations, including the use of AI, to train student's abilities to search for and critically select and synthesise information from different resources (lecture material, journal articles, books, AI) that might support their research question and inform their experimental study. Having to defend their work at the final poster session in front of peers and experts, students are trained in their ability to formulate own arguments, discuss alternative approaches, and anticipate the outcomes of their work (Figure 2).

While the task theme of experimental design primarily develops problem-solving and critical thinking skills, the didactic framework is designed to train social skills. Firstly, the project simulates not only real-world topics but also a realistic working framework. Just as in professional settings, the student groups must function effectively, which is supported by the creation of a group contract. This contract establishes guidelines for how the group will collaborate. As it is likely that students encounter challenging team dynamics now and later in their careers, the group work provides a learning environment to develop strategies for creating a positive team environment and managing team conflicts. To further support this goal, two short reflection activities are incorporated at different points during the group phase to encourage students to assess their group experience and learn how to improve it. Furthermore, peer feedback is built into the process, with students providing feedback to the members of their own group as well as on the work of other groups. These reflection and feedback activities aim at specifically fostering students' abilities to build relationships with others to work towards a common goal in a constructive atmosphere as well as to give and receive constructive feedback.

## 3. Challenges and (some) solutions to make PBE work with 350+ students

Despite the usefulness of PBE pedagogy, implementing project-based modules and managing the learning process remains challenging. We will discuss below the main challenges and present our solutions to some of them.

### 3.1 Infrastructural constraints

First, the teaching infrastructure at universities is often not adapted to the needs of group work activities, and suitable rooms for working in groups and presenting projects are missing, especially for large groups (e.g. several hundred students). Although many initiatives aim at providing space for project-based education – for example, dedicated maker spaces for students to perform projects or multifunctional rooms that can be used for both lectures and group work – these spaces can usually host only a limited number of students at a time. For large classes, however, group sizes should be kept small to ensure the maximal group experience to contrast the large lecture halls where an anonymous atmosphere prevails (Zhang L. & Ma Y., 2023). In the course presented here, the first editions of the project-based modules were held in the lecture halls, with up to 120 students and eight tutors working in parallel and various sequential tutoring sessions.

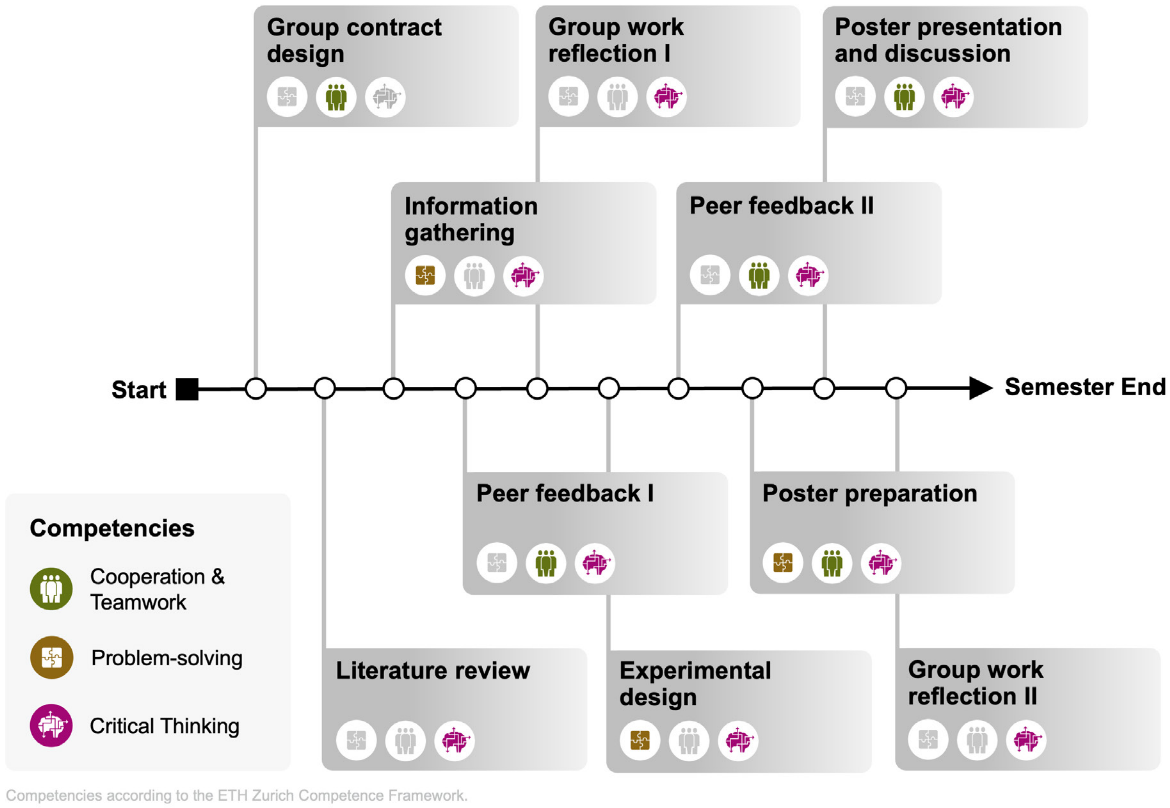


*Figure 2: Training 21st Century Skills in the group project phase: important milestones. Competency development at the different milestones is described in the text (ETH Competence framework: Copyright: ETH Zurich).*

Although this is possible, our experience clearly showed that separate rooms shared by 1 or 2 tutors are critical, as they greatly increased the quality of student-tutor and student-student interaction. Meanwhile, the group work sessions are held in seminar rooms, the number of which roughly equals the number of tutors involved. Universities will have to adapt their teaching infrastructure such that effective PBE will be possible with large groups, for instance, by transforming frontal lecture settings into smart classrooms, especially if project-based education is envisioned to be implemented for large classes and eventually, for many classes within various university curricula. ETH Zurich has recently started this process by building a dedicated facility for project-based education (PBLabs[2]) that offers flexible solutions for a variety of teaching settings for up to 120 students.

## 3.2 Management of the learning process

Besides infrastructural concerns, teachers adopting PBE may find it challenging to organize and oversee the learning process. This includes providing the learning materials, keeping up with students' personal and in-group collaboration progress, checking up on students' performance, providing timely feedback, and supporting sufficient interactions among students and teachers (Haatainen & Aksela, 2021). Hence, a solution that assists teachers in managing the mentioned efforts is highly desired. Especially for large classes, these efforts multiply dramatically, and consequently, one teacher cannot deal with PBE in a large class on his own but highly depends on co-teachers and/or assistants. In the teaching scenario we describe here, one lecturer took the lead for organizing and managing the group work. She is assisted by one or two senior teaching staff members and up to 25 student assistants (tutors) over the course of the group phase. The manager and the senior staff members are responsible for recruiting, training, and supervising of the tutors during the semester. The training includes a half-day workshop to convey didactic and organizational matters as well as several meetings during the semester to discuss the upcoming tasks, clarify questions and solve possible

[2] https://ethz.ch/en/the-eth-zurich/education/pblabs.html

problems. A 'buddy'-system, where a 'new' tutor teams up with an experienced tutor, ensures best support for new teaching assistants, and a chat is available for immediate questions and help. The tutors themselves are responsible for organizing the meetings with their groups, discussing the groups' progress, giving feedback on students' work and assessing students' performance during the entire group project phase. Each tutor spends between one and two hours per week with their groups. To perform their task, the tutors are provided with detailed documentation for the different steps of the group phase as well as on feedback and grading criteria to ensure that all tutors handle group management and evaluation in a comparable and fair way.

## 3.3 Student motivation

Problem-based methods can enhance motivation as centering learning around real-world problems is suggested to make learning more interesting and relevant for students. However, research has identified motivational challenges, including lack of participation or engagement (Winja, 2011; Winja et al., 2024). Thus, for students to fully engage with the project, it should be relevant to their study programme and future professions, aligned with the learning goals of the course, and spark their interest and their perceptions of meaningfulness. Thus, students' perceptions of the task value are critical aspects for motivation. The perceived value of a task has been described by Eccles & Wigfield to contain four factors: (a) intrinsic or interest value, (b) attainment value, (c) utility value, and (d) cost (Eccles & Wigfield, 2020; Winja et al., 2024). In the course described here, we aimed to increase the intrinsic interest value by tightly coupling the project with the course learning goals. The project serves to deepen the concepts taught in the course, e.g., types of genetic variations, principles of inheritance, expression of molecular traits, and gene technological methods by applying the taught concepts to a real-world example (an inheritable disease) in health science and medicine. The latter might also increase the perception of utility value: the task's usefulness for future goals such as excelling in academic or industrial research environments or in the public health sector.

As each task carries perceived costs (e.g., effort, time, anxiety), students tend to avoid tasks if the costs outweigh the benefits (Winja et al., 2024). Compared to attending lectures, where the invested time is clearly defined, students might have difficulties estimating the amount of time they need to invest in projects, thus, working on group projects might feel excessive if not rewarded otherwise. We therefore decided to award a bonus for the activities students solve during the semester apart from the in-class lectures. While these activities are generally ungraded (the final course grade is determined by a written exam), students can obtain bonus points for the successful completion of the exercises and the group project, which can contribute towards their final grade of the course. Although student can participate in the exam and receive grade 6 (highest grade) without any bonus points, over 90% of the students take part in the bonus system. The bonus point system not only motivates students to actively participate during the semester, but also provides regular feedback on students' learning progress, a benefit, which students often point out in the course evaluations.

## 3.4 Assessing the competencies fostered by project-based education

One of the most significant difficulties in project-based education lies in assessing the fostered transversal competencies. Unlike the measurement of simpler constructs such as factual knowledge, assessments that measure complex competencies need to consider the interrelationships between the individual elements contained within these competencies (e.g., attitudes, behaviours, or ways of acting and thinking) and account for them in the design of questions and evaluation scales. Often, subject-specific knowledge must also be included in the assessment to reflect real-life requirements. Furthermore, assessing these complex constructs requires the design of tasks that immerse the examinees in such complex constructs. Education, therefore, faces significant challenges in developing assessments that can measure '21st Century Skills.' While analytical skills can be evaluated with standard test items, such as well-designed multiple-choice questions, a truly comprehensive assessment of personal and interpersonal skills would go beyond multiple-choice tests and include measures that foster creativity, reveal learner's thought processes, and promote collaboration. How tasks should be designed to assess transversal skills, how these skills can be meaningfully evaluated and, especially, how such assessments can be scaled is not yet fully addressed in the current literature.

Given these challenges, we chose not to assess the transversal skills in a regular test. Instead, we included the group project in the above-described bonus point system to provide students with feedback on their competency development without interfering with the high-stakes nature of the course exam. While we do not directly assess the quality of the interactions between the students, the criteria applied to assess the group projects do consider aspects of collaborative and teamwork behaviour. Although many criteria focus on content correctness and the feasibility of the experimental design, some criteria are specifically aimed at evaluating transversal skills development. For example, collaboration & teamwork competencies are evaluated by allocating points for the quality of the group contract (e.g., does it clearly outline the students' expectations for collaboration?), the quality of peer feedback (e.g., was the feedback constructive and meaningful?) and the quality of the poster presentation session (presentations, questions, and discussions). Students receive feedback on their development of critical thinking skills by assessing the quality of their literature review, the originality of their experimental approach, the alternative solutions they anticipated, and the logical sequence of arguments during presentations. Thus, by allocating bonus points based on students' efforts in developing transversal skills, students receive feedback on both their individual and their team performance, allowing students to track their own competency development in this course.

## 4. Learnings from PBE: Results from student evaluations

Generally, the described course format is well-received by students and the course ranks among the top 10% courses in terms of course evaluation scores compared to other courses on this study level. Although theses centrally administered course evaluation forms do not address specific teaching formats, such as project-based education, students regularly leave comments about the course format in the evaluation form. While students highly appreciate the bonus point system, some remain sceptic about the group work, especially regarding the time investment and the perceived task value. To gain insights into aspects specific for the project-based education module in our course, we regularly collect student feedback anonymously on the course leaning platform. Here, we will discuss items from these questionnaires that directly relate to the project-based phase. The methods and a description of data analysis strategy is attached to appendix.

First, we were interested to understand what aspects are most important to students in the group project phase. Interestingly, although a few students have voiced they would like to be assessed on a more individual basis, individual grading had no great importance for the majority of students. This speaks in favour of our approach to weighting the individual assessment less heavily than the group assessment, although individual student assessments may allow students to better track and demonstrate their own competency development. However, the transparency of the grading was rated as being critical for almost 60% of the students, indicating that clear assessment criteria for transversal skills that are understood and applied equally by all evaluators are essential. Not surprisingly, the group working atmosphere was indicated as the most important aspect in group projects (Figure 3). In our approach, we take student's considerations about group work into account by emphasizing the importance of a group contract and encourage students to reflect on their working attitude as a group in the two self-reflection modules at the beginning and at the end of the course.

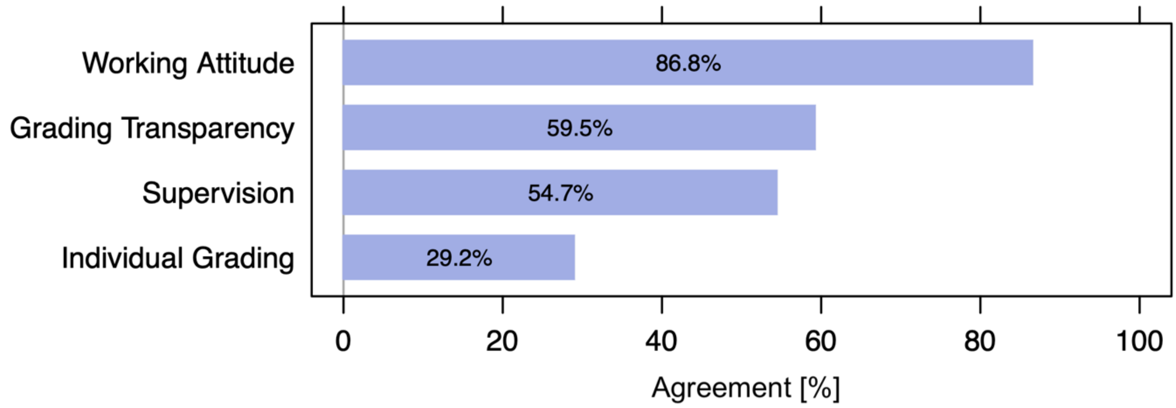


*Figure 3: Aspects rated by students as being critical for working on group projects on a binary scale (yes / no). Results from anonymous feedback forms collected over several years (n = 1359, numbers are aggregated results from 5 consecutive years from 2017 to 2021).*

Next, we gathered students' feedback on several aspects of the project phase, particularly regarding the effort invested and the effectiveness of the group work. Most students felt that their collaboration was productive (Figure 4, Table 2). However, students' perceptions on their investment into the group projects differed considerably, with nearly half of the students feeling that they had to acquire knowledge beyond what was described in the course objectives. This difference in perception may be linked to the heterogeneity of the group in terms of background knowledge and the time they invested in the task. Indeed, correlation analyses indicated a significant correlation between time spent on the project and the need to acquire additional knowledge ($r = 0.16$, $p < .05$). Students who reported spending more than 3 h per week on the project work were more likely to state that they had to gather a lot of additional knowledge. Given that project-based work often involves solving real-world problems, it is natural that students may need to go beyond the scope of the course. In future course iterations, it might be helpful to discuss this aspect with students to raise awareness.

The effectiveness of the project phase was investigated by asking students' perceptions on the relevance of the project work. Here, many students were uncertain about the extent to which the group project fostered their understanding of the course content (see Figure 4). Interestingly, students who felt that the group work was well suited to highlight the connections between the course topics also reported a greater benefit of the group work for deeper understanding of the course content ($r = 0.71$, $p < .0001$). Similarly, as stated above, the perceived relatedness of a project to the course goals might differ between student groups, depending on their prior knowledge, their interest in the topic, and the study programme they have enrolled in. Indeed, the perception of 'usefulness' differs significantly between students of the two study programmes, with medical students feeling less related to the topic of the group project (see Figure 5 and Table 3). As the group project focuses on experimental design, this might be less close to medical students whose prior goal is to become medical doctors. However, the rationale behind such experiments and the applied technologies are very relevant to medical doctors as they might encounter situations in which they need to consult patients about genetic diagnostic tools or decide on applying those. We therefore plan to provide slightly different frameworks for the group projects for both study groups by formulating some tasks more concretely around a story that represents an authentic situation for medical doctors (e.g., students are asked develop a technological pipeline to analyse patient samples in a clinical study or to defend their rationale for applying a certain technology in front of the board of head physicians in their hospital).

| Category | *n* | Mean (± SD) | Median | Min | Max |
|---|---|---|---|---|---|
| **Students' rating of critical aspects when working on group projects.** | | | | | |
| Working attitude | 1359 | 0.87 (0.34) | 1 | 0 | 1 |
| Grading transparency | 1359 | 0.59 (0.49) | 1 | 0 | 1 |
| Supervision | 1359 | 0.55 (0.50) | 1 | 0 | 1 |
| Individual grading | 1359 | 0.29 (0.45) | 0 | 0 | 1 |
| **Student feedback on students' investments and the effectiveness of the group work** | | | | | |
| Our group collaboration was productive. | 239 | 3.97 (1.20) | 4 | 1 | 5 |
| The group work was well−suited to highlight connections between the course topics. | 239 | 2.95 (1.23) | 3 | 1 | 5 |
| To complete the group work tasks, I had to acquire a lot of knowledge beyond the course objectives. | 239 | 2.88 (1.16) | 3 | 1 | 5 |
| The benefit of group work for deeper understanding of the course content was clear. | 239 | 2.84 (1.28) | 3 | 1 | 5 |
| **Student feedback on students' investments and the effectiveness of the group work by study major** | | | | | |
| ***Health Science and Technology BSc*** | | | | | |
| Our group collaboration was productive. | 169 | 3.99 (1.24) | 4 | 1 | 5 |
| The group work was well−suited to highlight connections between the course topics. | 169 | 3.01 (1.23) | 3 | 1 | 5 |
| To complete the group work tasks, I had to acquire a lot of knowledge beyond the course objectives. | 169 | 2.89 (1.15) | 3 | 1 | 5 |
| The benefit of group work for deeper understanding of the course content was clear. | 169 | 2.99 (1.21) | 3 | 1 | 5 |
| ***Human medicine BSc*** | | | | *1* | *5* |
| Our group collaboration was productive. | 70 | 3.93 (1.12) | 4 | 1 | 5 |
| The group work was well−suited to highlight connections between the course topics. | 70 | 2.83 (1.23) | 3 | 1 | 5 |
| To complete the group work tasks, I had to acquire a lot of knowledge beyond the course objectives. | 70 | 2.87 (1.20) | 3 | 1 | 5 |
| The benefit of group work for deeper understanding of the course content was clear. | 70 | 2.49 (1.38) | 2 | 1 | 5 |
| **Student evaluation of the tutor's coaching competences** | | | | | |
| Our tutor was always available for questions. | 239 | 4.72 (0.67) | 5 | 1 | 5 |
| The group evaluations were plausible to me. | 239 | 4.35 (0.91) | 5 | 1 | 5 |
| The tutor's feedback on our submissions was helpful and constructive. | 239 | 4.31 (0.91) | 5 | 1 | 5 |
| Our tutor communicated the tasks clearly. | 239 | 4.26 (0.96) | 5 | 1 | 5 |
| I received sufficient feedback during in−person sessions. | 239 | 3.94 (1.23) | 5 | 1 | 5 |

*Table 2: Descriptive statistics of the reported data.*

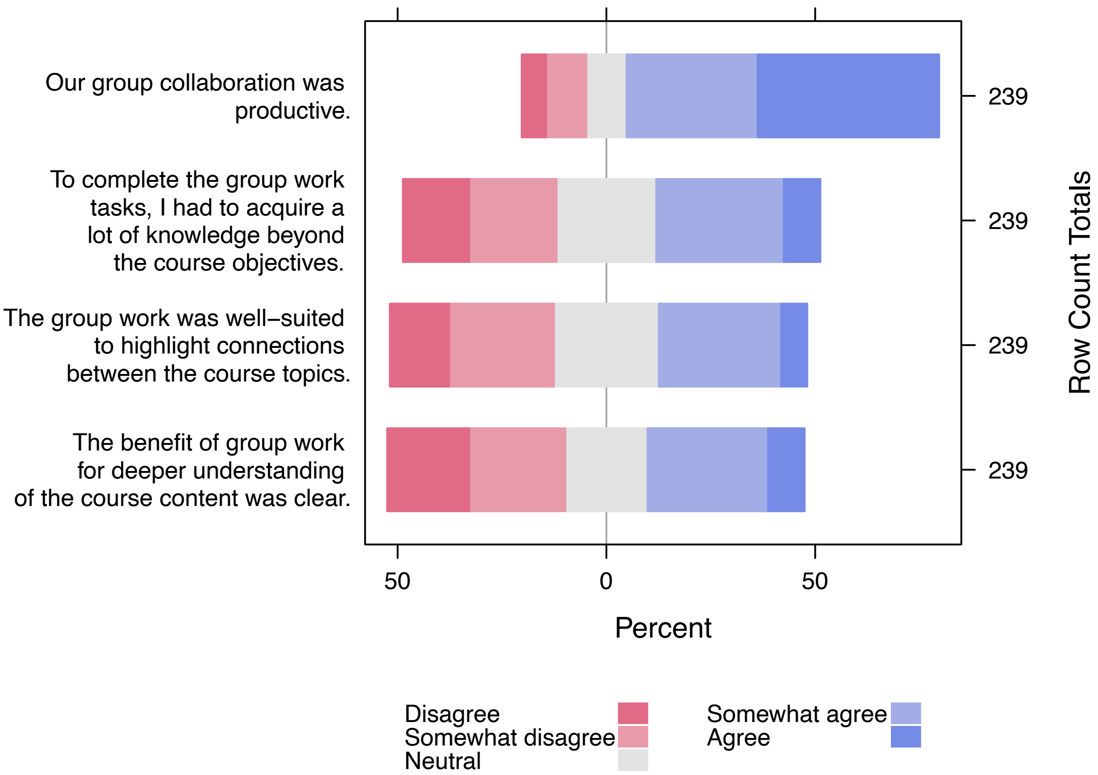


*Figure 4: Student feedback on aspects related to students' investments and the effectiveness of the group work (answers provided on a 5-point Likert scale, data from the cohort of autumn semester 2023, n = 239). Descriptive statistics are shown in Table 2.*

Finally, we also asked students for their feedback on the competences of the tutors. Students were very satisfied with the coaching performance regarding the tutor's openness to answer their questions, the explanations of the tasks, the feedback during the project phase and the final evaluation of their work. Some students would have liked to receive even more feedback from their coaches. In addition, many students left very positive comments on their individual tutors, indicating the quick response time of their tutor to their requests, their accommodating approach and patience, and their abilities to explain difficult content.

In summary, the evaluation results are promising, indicating that the project-based approach is effective in many aspects. Students appreciated interacting with the tutors and acknowledge the tutor's efforts in creating a pleasant and constructive working atmosphere. In line with this, the majority of students felt that their group work was productive. The evaluations also highlighted an area of improvement, as one student group expressed a lower sense of relatedness, encouraging us to further refine our approach of project-based education.

| **Category** | $n_{HST}$ | $n_{MED}$ | **W-Statistic** | *p-Value*[1] | *r* |
|---|---|---|---|---|---|
| Our group collaboration was productive. | 169 | 70 | 6321.5 | 1 | 0.06 |
| The group work was well−suited to highlight connections between the course topics. | 169 | 70 | 5967.5 | 1 | 0.01 |
| To complete the group work tasks, I had to acquire a lot of knowledge beyond the course objectives. | 169 | 70 | 6370.5 | 1 | 0.06 |
| The benefit of group work for deeper understanding of the course content was clear. | 169 | 70 | 7207.0 | > .05 | 0.18 |

*Table 3: Statistical analysis of group comparisons on students' investment and group work effectiveness r: Wilcoxon effect size; HST: Health Science and Technology BSc; MED: Human Medicine BSc. [1]p-value was Bonferroni-corrected for multiple testing.*

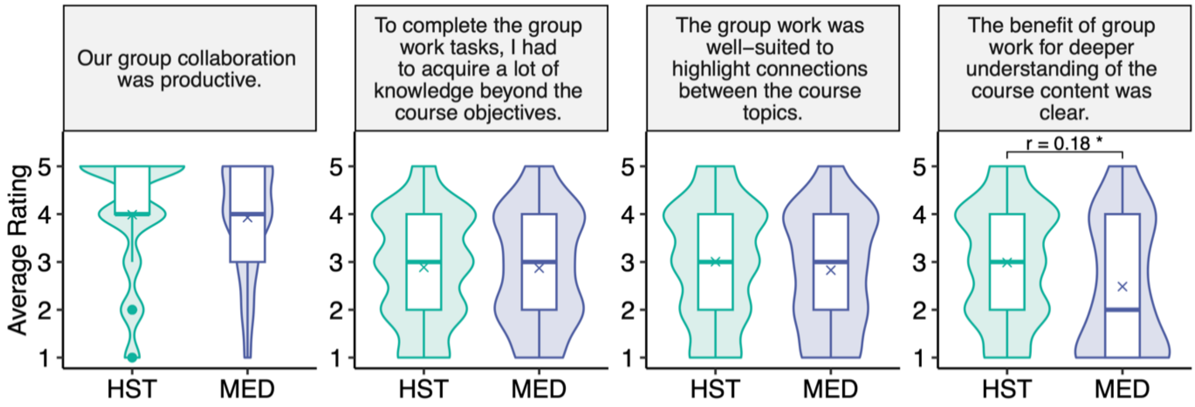


*Figure 5: Student's perceptions on different aspects of the group project phase varies for students from different study programmes. Horizontal bars indicate medians, × indicates the group means, violin plots indicate the data density underlying the boxplot data, colored dots indicate single data points. Descriptive statistics are shown in Table 2, results from the statistical comparison in Table 3 (data from cohort of autumn semester 2023, n = 239).*

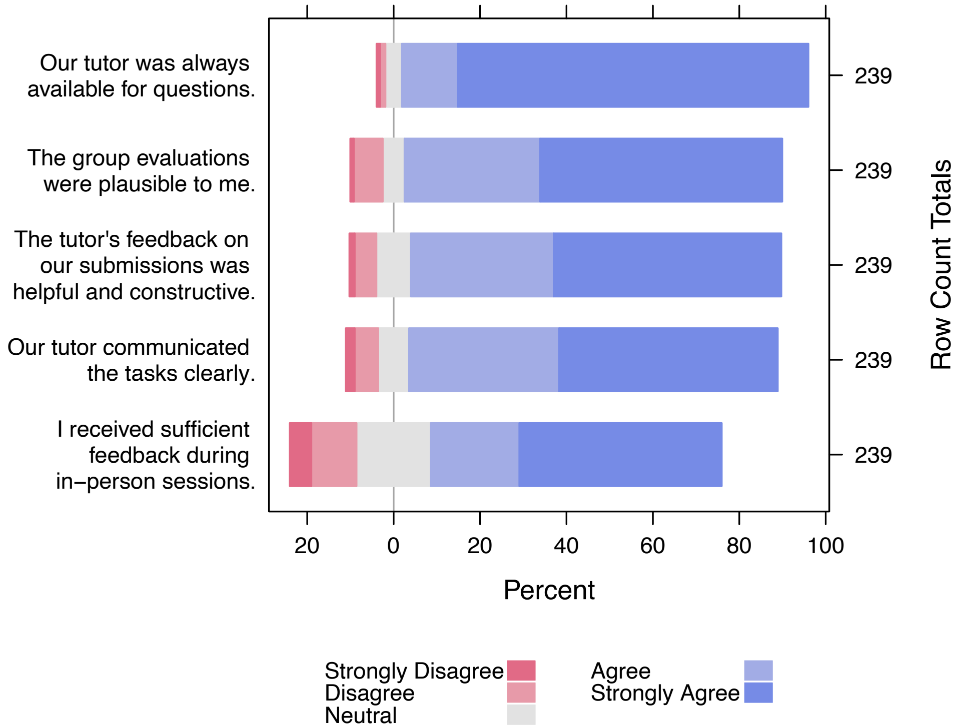


*Figure 6: Student evaluation of the tutor's coaching competences. Descriptive statistics are shown in Table 2 (data from the cohort of autumn semester 2023, n = 239).*

## 5. Implications for curriculum development

21st Century Skills are essential for effectively applying technical competencies in both the workplace and society. To meet these demands, university education must evolve by placing a greater emphasis on promoting such skills. Many universities are already aligning their educational programs towards these goals, offering various courses, workshops and opportunities to develop transversal competencies (e.g., KU Leuven[3], Columbia University, Princeton University). However, integrating transversal skill development into standard courses, which typically focus on methodological and disciplinary knowledge, remains a challenge.

[3] https://www.kuleuven.be/english/education/higher-education-advancement-fund/future-proof-programme-portfolio/Transversal-skills-for-the-21st-century

Teaching 21st Century Skills using project-based education has important implications for curriculum development, as it requires a fundamental shift from traditional content-based instruction (and examination) to a focus on skills like critical thinking, creativity, and collaboration. Thus, curricula need to incorporate objectives beyond subject mastery, emphasizing competencies that prepare students for real-world challenges. Since traditional exams do not measure 21st Century Skills effectively, frameworks for assessing students' development of complex skills, such as teamwork, need to be designed in order to align the curriculum goals with skill mastery.

The framework we propose in this paper demonstrates how project-based education can contribute to fostering methodological, social, and personal skills in a large, discipline-specific introductory course for first-year students. This model can inspire or enhance similar efforts in other courses and study programmes. Although certain challenges, such as infrastructural constraints, are more difficult to overcome, universities can support departments and institutes in developing project-based courses by enhancing educational support and creating lecturer or teaching staff positions, with the latter being critical to sustaining these initiatives on a longer term. Ultimately, these measures will facilitate shifting curriculum development towards providing students with opportunities to engage in meaningful projects that serve to develop skills needed in the modern world.

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# Appendix

## Methods

### *Participants*

Survey data from 1598 first-semester students enrolled in two different study programs ('Health Science and Technology' and 'Human Medicine') at ETH Zürich, Switzerland, were combined in this study. Demographic data were not assessed. Participation in the surveys was voluntary; however, completing the questionnaires was one of several requirements to receive an additional end-of-semester bonus of 0.25 grade points on the final exam grade.

### *Questionnaires*

The administered self-developed questionnaires addressed different aspects of group work as well as students' ratings of their teaching assistants. In the student cohorts from the autumn semesters of 2017 to 2021 ($n$ = 1359), students were asked about critical aspects of group projects on a binary scale (yes/no) based on a predefined list of four items: working attitude, grading transparency, supervision, and individual grading. In the student cohort of the autumn semester 2023 ($n$ = 239), responses were collected in more detail regarding students' investment in group work and their perceived effectiveness for personal learning gains. These responses were measured using a 5-point Likert scale questionnaire. To assess students' evaluations of their tutors' coaching competencies, an additional 5-point Likert scale questionnaire with five independent items was administered to the autumn 2023 cohort.

### *Data analysis*

The questionnaire data regarding critical aspects of group work, students' investment in group work, and tutor evaluations were analyzed descriptively and visualized. Descriptive statistics are summarized in Table 2. Students' investment in group work and its perceived effectiveness in the autumn 2023 cohort were further analyzed by comparing ratings between the two study programs. To do so, a Wilcoxon Rank-Sum Test for independent samples with a non-normal data distribution was applied to investigate group differences between the two cohorts ('Health Science and Technology' and 'Human Medicine'). *p*-values were Bonferroni-corrected to adjust for multiple testing. The Wilcoxon effect size *r* was determined for each comparison using the following classifications: $0.1 \leq r < 0.3$; medium: $0.3 \leq r < 0.5$; large: $r \geq 0.5$.