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Designing a MOOC for primary and middle school science teachers

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Abstract

This study examines the effectiveness and participant satisfaction of the massive open online course (MOOC) "questione di cellule (QdC)," designed for primary and middle school science teachers in Italy. Developed by the University of Padua, the course addresses a gap in teacher training for cellular biology in Italy. With a 49% completion rate among 1,100 enrollees, the MOOC showed high levels of satisfaction regarding content quality, clarity, and classroom applicability. Learning outcomes and quiz performance indicate effective knowledge acquisition, particularly among participants with lower initial scores. Video lectures and classroom-oriented resources were especially appreciated. Overall feedback supports the MOOC's effectiveness in providing accessible, high-quality science education for teachers, while also highlighting areas for improvement, such as strengthening online interaction and expanding inclusive resources for diverse learning needs.

Keywords: cellular biology, continuous professional development, science education, teacher training

INTRODUCTION

Context, Educational Need, and Relevance of Cellular Biology

The massive open online course (MOOC) "questione di cellule (QdC)" ("cell matters" in English, see the logo in **Figure 1**) is a MOOC on basic cell biology, designed primarily for primary and middle school science teachers, but open to other people interested (for example university students and scientific educators). It was created by the department of biomedical sciences at the University of Padua (Italy) and published on the EduOpen platform, the first Italian portal of free online university courses supported by the Ministry of Education.

Neither among the MOOCs offered by the University of Padua nor on the EduOpen platform were there biology training courses specifically dedicated to primary and middle school science teachers. An analysis of other Italian MOOC platforms (Politecnico di Milano, https://www.pok.polimi.it/, University of Bologna, https://book.unibo.it/, and University of Naples Federico II, https://www.federica.eu/) revealed a similar lack of life sciences training initiatives targeting this audience. Moreover, a snapshot taken in February 2022 on the Sofia website of the Italian Ministry of Education and Merit (a platform where Italian teachers can find many training initiatives offered in the online catalog by schools and subjects accredited/qualified by the Ministry of Education) showed that, among 144 courses retrieved using the keywords "sciences" or "biology," the vast majority were targeted at high school teachers. Only four could also be considered for primary school teachers, and, among these, only three of these are offered by higher education institutions.

Cellular biology plays a crucial role in science education. The functioning of cells is fundamental to all natural sciences, which children first encounter systematically in school. Many topics of general interest (such as genetics, nutrition, and ecology) can only be properly understood with a solid knowledge of cellular processes. While teachers may choose the depth at which these topics are addressed depending on class needs, they must be adequately prepared to respond to students' questions, which requires a robust disciplinary background.

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Contribution to the literature

- This study provides empirical evidence on the effectiveness of a MOOC specifically designed primarily for primary and middle school science teachers in Italy but also attended by pre-service teachers and students interested in science education, addressing a significant gap in teacher training for cellular biology. The high completion rate (49%) and positive feedback validate the MOOC's ability to meet the needs of a broad audience seeking accessible, high-quality science education resources.
- This study offers insights into the design and implementation of MOOCs for teacher professional development and early-career training, highlighting the success of short video lectures combined with practical classroom resources. This approach proved highly effective in engaging participants with diverse educational backgrounds, professional experience, and geographical distribution.
- By identifying areas for improvement, such as enhancing online community building and adding more inclusive resources for diverse learning needs, this research contributes to the ongoing discourse on optimizing MOOCs for continuous professional development and pre-service training in STEM fields.

Figure 1. "QdC" logo as appears in EduOpen platform (Source: Authors' own elaboration)

Teachers' Professional Development Needs and Instructional Challenges

The MOOC "QdC" was designed to respond to this clearly identified educational gap. International evidence highlights critical challenges in science education in Italy According to the OCSE-PISA 2022 survey (https://www.oecd.org/pisa/), Italian students scored 477 in science literacy, below the OECD average of 489 and showing a decline compared to 2015. In addition, data from the OECD teaching and learning international survey (https://www.oecd.org/en/data/datasets/talis-2018-database.html) indicate that only 64% of Italian teachers received comprehensive initial training in subject content, pedagogy, and classroom practice, compared to an OECD average of 79%, and that participation in induction activities remains markedly lower than in other OECD countries.

Previous research in biology education has documented persistent misconceptions in cellular biology that hinder both student and teacher understanding of foundational concepts, including cell structure, organelle function, membrane transport, and cell division (Silaban & Pranoto, 2024). These learning difficulties are often related to the abstract and non-observable nature of cellular phenomena, which limits learners' ability to visualize microscopic structures and link them to biological processes.

Consistent with these findings, similar challenges have emerged through years of dialogue between the "QdC" teaching team and in-service primary and middle school teachers. The design of the MOOC "QdC" was therefore intentionally aligned with these needs. In particular, the course integrates dynamic visualizations and simulations to support conceptual understanding, multi-representational resources to connect different biological scales, scaffolded explanations to manage terminological complexity, and inquiry-oriented activities aimed at strengthening teachers' ability to relate cellular structure and function in classroom practice.

Teachers often lack the background and resources to connect scientific content to students' experiences. For this reason, it is crucial to support continuous and well-structured professional development, encompassing four key dimensions

(a) personal development,

(b) in-service achievements,

(c) teaching competence, and

(d) scientific training (Kedraka, 2008).

The continuous professional development formative paths are essential lifelong learning programs aimed at supporting the development of a new kind of educator (Hammerness et al., 2005),

> who constantly looks for professional development programs, in order to enrich and improve one's personal portfolio. These programs

> are now a fundamental element of educational quality and are related to the professional identity of the teacher, its adaptation to the new data of education and its self-efficacy (Tzovla et al., 2021a, p. 1).

In many Italian schools, unlike in other European countries, there are no dedicated science laboratories or specific support resources, often leaving instructional design to individual teachers' creativity.

To address these challenges and foster teachers' professional growth in a flexible, self-paced manner, the "QdC" MOOC was designed and implemented.

MOOC Features: Evidence From the Literature

MOOCs represent open educational resources that have advanced significantly, expanding in quantity and revolutionizing teaching and learning methodologies. They arise as innovative pedagogical methods aimed at tackling intercultural challenges, with the goal of fostering inclusivity and fulfilling educational requirements through an accessible and widely-distributed approach. Moreover, they hold promise in revolutionizing instructional techniques, facilitating knowledge acquisition, and nurturing professional growth and competencies. MOOCs offer worldwide learning prospects, grant access to openly available resources, and play a pivotal role in enhancing the quality of higher education (Baturay, 2015; Carson & Schmidt, 2012; Daradoumis et al., 2013; Lackner et al., 2014; McAuley et al., 2010).

MOOCs are based on digital platforms that allow students to participate in courses across different subjects: these courses offer free access to experts', along with ongoing learning support through diverse activities and educational resources. MOOCs are increasingly popular in both national and international educational settings, with prestigious institutions embracing the trend and creating various MOOCs across different countries and fields (Jung & Lee, 2018; Picasso et al., 2023; Veletsianos & Shepherdson, 2015).

In 2008, George Siemens pioneered the first MOOC, attracting thousands of students to explore emerging trends in online learning. These early MOOCs, called cMOOCs, emphasized a connectivist approach, where knowledge is seen as a networked state, and learning occurs through building connections via online and social technologies. cMOOCs are constructivist in nature, allowing learners to contribute to the course without standardized exams or completion certificates (Rouveix et al., 2020).

A few years later, xMOOCs were launched: these courses featured formal content, video lectures, graded assignments, and final exams, offering completion certificates. xMOOCs recreated the conventional teacher-student model, positioning educators as information providers and learners as consumers.

Over time, quasi-MOOCs also emerged, offering asynchronous learning materials but lacking the social interaction of cMOOCs and the automated grading or structured format of xMOOCs (Carson & Schmidt, 2012; Daradoumis et al., 2013; Lackner et al., 2014; McAuley et al., 2010; Picasso et al., 2023).

The learning management system used in these courses collects data on participants' online behavior, offering valuable insights into learning processes and the connection between online activity and academic performance. This data can help educators identify when interventions are needed or when course activities should be adjusted to enhance learning outcomes (Daradoumis et al., 2013; Mirriahi & Dawson, 2013; Picasso et al, 2023).

The decision to create a training course in the form of a MOOC was made for several compelling reasons:

- **Broad reach:** A MOOC can reach a large number of teachers across Italy, breaking geographical barriers.
- **Flexibility:** The asynchronous format allows teachers to engage with the course at times and places that suit their schedules, enhancing accessibility and convenience.
- **Cascading impact:** MOOCs have the potential to indirectly benefit a vast number of students through the improved skills and knowledge of their teachers.
- **Scalable professional development:** The ability of MOOCs to provide professional development on a large scale is crucial in working towards the ambitious goal of ensuring quality education for all.

The "QdC" MOOC is an xMOOC, a traditional course where participants can acquire content. The "QdC" MOOC provides useful videos for teacher professional development and also includes numerous resources (infographics, scientific and historical insights, games) specifically designed to be carried out in the classroom and to allow for active learning. Teachers can thus choose the materials that best suit the characteristics of their classes and their own teaching style. Based on the authors' extensive experience, primary and secondary school teachers face a highly demanding workload. They are actively seeking scientifically accurate, clear, and accessible materials to support them in both planning and delivering their lessons.

Research Gap and Aims

While MOOCs for teacher professional development have been widely discussed in the international literature, and some Italian studies have examined MOOC-based professional development in mathematics, physics, and STEM education (Piroi et al., 2023; Taranto, 2020), empirical research focusing on biology—particularly cellular biology—for primary and middle school teachers in Italy remains very limited. Moreover, few professional development initiatives have been implemented as MOOCs specifically targeting the teaching of biological concepts in primary and middle schools.

Beyond addressing this national gap, the present study contributes to the international literature on MOOCs and teacher professional development in three main ways. First, it provides empirical evidence on a discipline-specific MOOC in the life sciences, an area that is less represented compared to mathematics and other STEM disciplines. Second, it investigates how a structured xMOOC can support teachers not only in content learning but also in translating complex scientific concepts into classroom practice. Third, it proposes a replicable design model that conceptualizes MOOCs as structured tools for large-scale professional development, rather than solely as open-access learning environments.

To the best of our knowledge, this study represents the first empirical study in the Italian context examining the design, implementation, and impact of a biology-focused MOOC for the professional development of primary and middle school teachers. Building on previous international work (e.g., Tzovla et al., 2021b), which explored the satisfaction of in-service elementary school teachers (251 teachers enrolled in the MOOC of whom 142 completed the course) enrolled in a MOOC focused on teaching biological concepts in primary schools, the aim of this research is to investigate participants' satisfaction, perceived applicability of the content, learning outcomes, and insights from a focus group, in order to address the following research questions:

- To what extent did participants understand and internalize the course content, as evidenced by their performance on the various quizzes?
- What is the level of teacher satisfaction with this type of content delivery method?
- How satisfied are teachers with the level and quality of the content provided?
- What insights can be gained from a focus group with selected MOOC participants?
- To what extent can teachers apply the course content in their classrooms, and what is their feedback on its practical applicability?

MATERIALS AND METHODS

MOOC Funding and Fulfillment

The "QdC" MOOC project was funded by the University of Padua through a competitive call dedicated to third mission initiatives, aimed at public engagement and interaction with the local community. The project was developed in collaboration with two partner schools. A scientific consultant and a graphic designer with expertise in cellular biology also contributed to the project. The adequacy of the content created (video lessons and proposed educational activities) was verified with some teachers from the pilot schools. Finally, the MOOC was published on the EduOpen platform. The development of the MOOC took approximately one year (see **Figure 2** for the Gantt chart).

The design of the training program is grounded in the analysis, design, development, implementation, and evaluation (ADDIE) model (Bonaiuti & Dipace, 2021), a widely used framework for planning and managing educational interventions in both face-to-face and online settings. The model consists of five phases—analysis, design, development, implementation, and evaluation—which together describe a cyclical and systematic instructional design process. Each phase contributes to the coherent development of the educational project, as outlined below.

1. **Analysis:** This initial phase was focused on the analysis of the OECD and Coursera data and the overview of the Italian educational context, including the features of the learners, available resources, time constraints, and training needs. The aim of this phase was to collect important information about possible participants in order to target the design of the MOOC program.
2. **Design:** The design phase involved planning the training pathway in detail on the basis of data collected through the analysis phase. Learning objectives, content, instructional materials, assessment strategies, and the professionals involved were identified. During this stage, the overall structure of the program was defined in a systematic manner, ensuring alignment with the educational goals related to the target.
3. **Development:** In this phase, the planned elements were translated into concrete outputs. Instructional materials such as slides, digital learning objects, videos, forum planning and other resources were produced, and the learning environment was created and adapted. This is the operational stage in which the project took shape.
4. **Implementation:** The training program was then delivered to the target learners, through an online format. This phase corresponds to the delivery of the course, during which learning processes were monitored–through the various modules, activities and forum–and participants are supported throughout their learning experience.
5. **Evaluation:** The final phase involved assessing the outcomes of the training intervention at

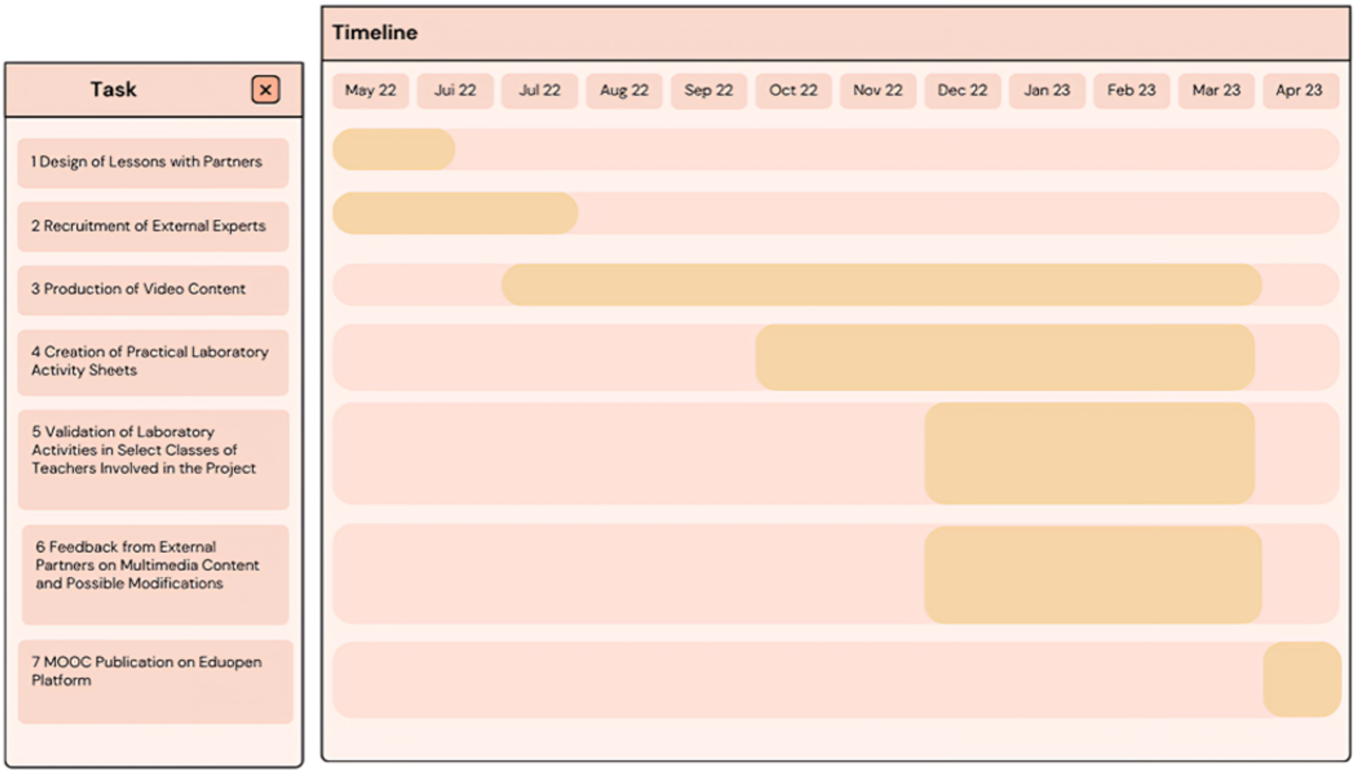

Figure 2. Gantt chart for the implementation of "QdC" MOOC (Source: Authors' own elaboration)

multiple levels. These included learners' reactions and satisfaction and the level of learning achieved with a pre and post training analysis (Bonaiuti & Dipace, 2021).

In general, the ADDIE model provided a structured and theoretically grounded framework for the design and development of the MOOC, ensuring coherence between pedagogical intentions and instructional choices. By adopting the ADDIE model, the MOOC's design process was made explicit and transparent. Without such a conceptual foundation, it would be difficult to justify design decisions or to understand the mechanisms through which teacher learning is expected to occur. The structure of this MOOC, which comprehends videos, activities, quizzes and forum, aimed at sustaining teacher continuous professional development. As the literature affirms, teachers participating in MOOCs for continuous professional development (pdMOOCs) can take responsibility for their own learning, as they are actively engaged in inquiry processes that involve using learning resources, seeking assistance and support, observing and learning from peers' strategies, adopting self-regulated learning practices, and collaborating with others to achieve their learning goals (Koukis & Jimoyiannis, 2017; Koutsodimou & Jimoyiannis, 2015; Littlejohn et al., 2016).

MOOC Scientific Content

The course addressed fundamental concepts of cell biology through short video lessons, composed of explanatory drawings and animations related to the topics covered. This format was chosen for its accessibility and effectiveness, as audiovisual materials are often more engaging than text-based resources. Additionally, it allows the combination of spoken explanations with images and animations that help clarify concepts that can sometimes be very complex.

As a pilot experience, the MOOC was designed for Italian teachers and therefore tailored to the primary and middle school Italian ministerial programs. The criteria guiding content development were:

- **Scientific accuracy:** All texts and graphics were carefully reviewed in collaboration with experts.
- **Clarity of presentation:** The language was kept as simple as possible, using short and direct sentences, and all scientific terminology was explicitly explained.
- **Use of analogies and everyday examples:** Familiar situations were frequently used to make complex concepts more accessible.

MOOC Design

The MOOC was organized into three modules, one for each topic:

(1) cells as the basic units of living organisms,

(2) cellular reproduction, and

(3) how cells communicate and specialized cells.

Each module included four 7-minute video lectures covering essential content. Videos were carefully

Table 1. Structure of the "QdC" MOOC

Module	Explanation
Module 1	Cells as the basic units of living organisms
Objectives	Understand the differences between prokaryotic and eukaryotic cells, animal and plant cells. Describe the molecular constituents of cells and their characteristics. Learn the functions of the organelles that make up a eukaryotic cell.
Video lessons	1.1. The prokaryotic and eukaryotic cell 1.2. Cell components: Proteins, nucleic acids, lipids, carbohydrates 1.3. Structural elements of the cell, part 1 1.4. Structural elements of the cell, part 2
Module 2	Cellular reproduction
Objectives	Understand the mechanisms by which DNA is duplicated in the cell. Learn how cell division or mitosis occurs and the flow of genetic information: from DNA to RNA and from RNA to protein. Familiarize yourself with some basic concepts of genetics.
Video lessons	2.1. The organization and duplication of DNA 2.2. Cell division 2.3. The story of a protein 2.4. Genetics
Module 3	How cells communicate and specialized cells
Objectives	Understand what languages cells use to communicate with each other. Learn the specificities of muscle, nervous and immune system cells.
Video lessons	3.1. Cells in dialogue 3.2. Specialized muscle cells 3.3. Specialized nervous cells 3.4. Specialized immune system cells

scripted, scientifically validated, and linguistically revised to ensure clarity and accessibility. Tutors' faces were not shown; narration adopted a conversational style, with alternating voices and frequent questions to support learners' attention. Explanatory images and animations were used to illustrate key concepts. Each video started with a general guiding question and concluded with a brief summary of the main points.

The main MOOC's structure is described in **Table 1**.

The limited duration of the MOOC did not allow all topics related to cell biology to be addressed. To identify priority topics, the course design was developed in collaboration with the partner schools. Experienced teachers reviewed a preliminary version of the course and provided feedback on topics that typically raise students' curiosity, as well as on presentation approaches considered useful for classroom activities.

Based on these suggestions, additional resources were included in each module in different formats to address common questions raised by teachers and students. These resources comprised in-depth scientific explanations of key biological concepts, historical materials such as scientists' biographies, infographics, and proposals for practical classroom activities. All the resources for each module are presented in **Table A1** in **Appendix A**. Classroom activities were specifically designed for primary and middle school levels and were accompanied by all necessary supporting materials.

MOOC Research Instruments and Data Collection

Several activities were designed to collect data. Upon enrolment, an anonymous introductory questionnaire gathered demographic and professional information, including age, occupation (primary or middle school teacher, or other), years of teaching experience, subject taught, and region of origin. An initial multiple-choice quiz (pre-test), consisting of 10 questions, assessing basic biology knowledge. evaluated prior knowledge. At the end of each module, a 10-question quiz with multiple item types multiple-choice, sentence completion, insertion of specific terms into figures, and true-false) had to be completed. A minimum score of 6 out of 10 (corresponding to 60% correct answers) was required to pass; with unlimited attempts allowed. Completion was mandatory to access the subsequent module. At the end of the course, a final quiz covering all three modules required a minimum score of 7 out of 10 and could be repeated up to five times. A feedback questionnaire on overall satisfaction with the MOOC was also completed. Tutors were available for scientific and technical questions, and a forum facilitated communication with tutors and peer interaction. No time limit was set for completion of the MOOC, allowing learners to progress at their own pace. The assessment instruments were systematically aligned with the MOOC's learning objectives, with items designed to cover each objective. To ensure content validity, the instruments were reviewed by two experienced instructors involved in course design.

An analysis of the MOOC was conducted one year after its launch on the EduOpen platform. The course was launched in early April 2023, and the data were collected in early April 2024. In February 2024, a focus group via Zoom was conducted with ten active learners to discuss strategies for course improvement. At the end of the meeting, attendees were invited to voluntarily complete an additional feedback form to explore whether and how the provided resources were used in classroom practice. The same questionnaire was subsequently distributed to all learners through the forum. The data collected from the focus group activity were analysed through a qualitative content analysis implementing Atlas.Ti 2025 tool.

Data Analysis

Data collected from the initial test, the final quiz, and the final feedback questionnaire were analyzed to assess instrument reliability, item characteristics, and learning outcomes. Analyses were conducted on the following defined groups: enrollees (N = 1,100), defined as all individuals who registered for the MOOC but did not engage in any course activities; active participants (N = 868), who completed the pre-test and initial survey and whose questionnaire data describe participants' profiles; and completers (N = 535), whose data were used for the pre- and post-test, satisfaction, and feedback analyses. These group sizes refer to the time at which the analyses were conducted. All data were collected anonymously. No personal code was required for the evaluation survey. All data were securely stored and accessed exclusively by the researchers for analysis purposes (Brouwer et al., 2022). All statistical analyses were performed using Microsoft Excel. Internal consistency of the true/false items of the final quiz was evaluated using Kuder-Richardson formula 20 (KR-20), which is appropriate for dichotomous items. Classical item analysis, including item difficulty and discrimination indices, was conducted for the multiple-choice items of the final quiz to evaluate the quality of individual items. Internal consistency of the final feedback questionnaire, composed of seven Likert-scale items (1-6), was assessed using Cronbach's alpha, a standard measure of reliability for ordinal scales. Learning outcomes were evaluated by comparing pre- and post-test scores using paired-sample t-tests, which assess whether the mean difference between two related groups is statistically significant. Effect sizes were calculated using Cohen's d to quantify the magnitude of any observed differences.

RESULTS AND DISCUSSION

MOOC Enrolment, Participant Groups, and Completion Rates

One year after the opening of the MOOC, 1,100 learners enrolled on the platform . Among them, 868 completed the initial questionnaire and entrance test (pre-test), and are hereafter referred to as active participants. A total of 535 completed the entire course and received their final certificate and are hereafter referred to as completers. In our experience, these numbers represent a notably high level of engagement for this type of course, such as

> the prevalence of low completion rates and accordingly high dropout rates often became a central argument for MOOC critics in the MOOC discourse [...] many participants who sign up for a MOOC do not engage in any activities within the course; some of them do not even begin the MOOC" (Bozkurt, 2021; Celik & Cagiltay, 2024, p. 446; Lackner et al., 2015).

For example, Celik and Cagiltay (2024), in their study, developed an overview about the MOOC completion rates from three different perspectives (enrolled learners, active learners, and learner intentions) in four different MOOCs. Moreover, Jordan (2014) focused the analysis in terms of initial trends in enrolment and completion taking into account 91 MOOCs for enrolment numbers and 42 MOOCs for completion from three main MOOC portals (Coursera, EdX, and Udacity). In relation to the completion rate results, the evidence which emerged was that the completion rate changed between 0.9% and 36.1%, but in general, 5% completion rate was the typical rate (Celik & Cagiltay, 2024; Jordan, 2014). In the case of the MOOC "QdC," the completion rate is 49%, which is statistically much higher than the average completion rate reported by Jordan (2014) and Celik and Cagiltay (2024). Finally, as for the study of Tzovla et al. (2021b), the elevated course completion rate offers evidence that the course was responsive to teachers' needs and contributed positively to their self-efficacy beliefs.

MOOC's Active Participants' Profile

The data collected through the initial mandatory questionnaire (868 questionnaires, corresponding to active participants 79% of the total enrollees) provide a general description of the profile of the people who decided to enroll in the course. These descriptive quantitative data provide a general profile of active participants and are particularly useful for understanding whether the proposed training reached its intended target audience (see **Figure 3**). As expected, 60% are in-service teachers, both from primary (26%) and middle school (29%). Notably, 30% of active participants are students who have not yet obtained a degree: we can speculate that they are interested in teaching science subjects or are studying to become teachers.

This heterogeneity of the participant population represents an important methodological consideration. The substantial participation of pre-service teachers,

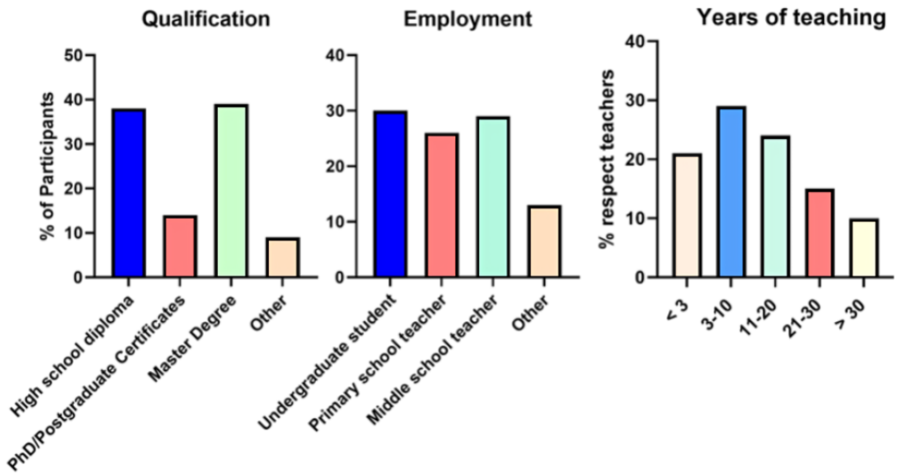

Figure 3. Data about the MOOC's active participants (Source: Authors' own elaboration)

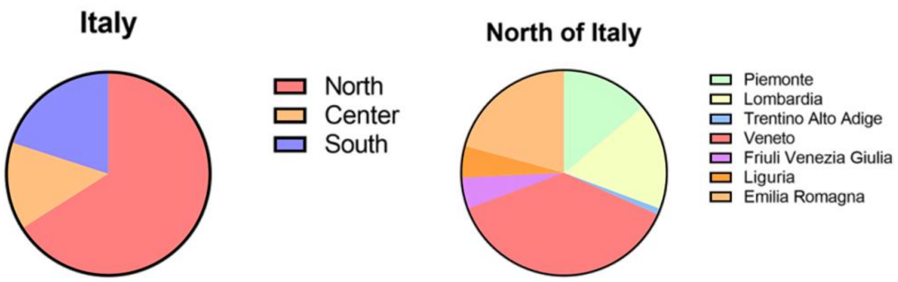

Figure 4. Geographic distribution of active participants (the University of Padua is located in the Veneto Region) (Source: Authors' own elaboration)

who may become teachers or science communicators, highlights the importance of providing early access to high-quality professional development opportunities for future educators. Such diversity is also consistent with previous research showing that MOOCs frequently attract learners at different professional stages (Milligan & Littlejohn, 2017). Accordingly, the results of the present study should be interpreted as reflecting the overall experience of a diverse group of active participants rather than a homogeneous teacher-only population.

A wide range of educational backgrounds and professional experiences is also represented among the active participants. Many active participants with advanced educational qualifications (40% hold a university degree, 30% a master's or PhD) took the course, indicating that its value lies not only in the content but also in how it was made accessible for use in the classroom. 38% of the active participants have a high school diploma. Regarding teaching experience, the presence of teachers with varied levels of experience (less than 3 years: 21%, 3-10 years: 29%, 11-20 years: 24%, 21-30 years: 15%, and more than 30 years: 10%) suggests that a thorough treatment of content and new teaching and learning approaches are valuable for teachers at all stages of their careers (see **Figure 3**).

The geographical distribution of active participants is noteworthy (see **Figure 4**). Active participants are distributed throughout the country, with a majority (66%) from northern Italy, but with significant representation from central Italy (14%) and southern Italy (20%). This distribution approximately reflects the population distribution in Italy (www.istat.it).

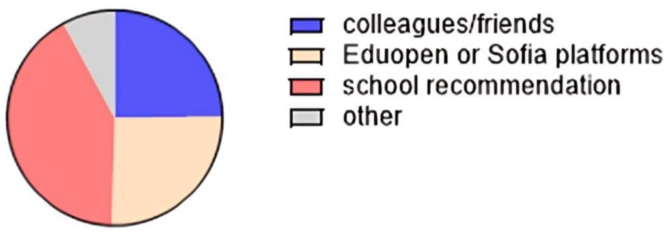

Figure 5. Pie chart showing the percentages of how MOOC active participants learned about it (Source: Authors' own elaboration)

The prevalence of active participants from the northern region is only partially due to the presence of the University of Padua. The Veneto Region, where the University is located, accounts for 25% of total enrolments, which may be attributed to trust in a well-known institution. However, all northern regions are well represented, confirming widespread interest in the MOOC regardless of the region of origin.

As shown in **Figure 5**, the majority of active participants learned about the course through school communication (42%), while 26% found out about it

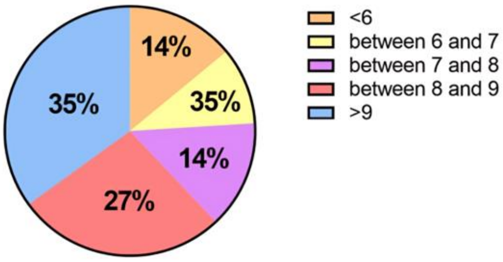

Figure 6. Distribution of scores obtained in the initial quiz by MOOC active participants (Source: Authors' own elaboration)

from the EduOpen and Sofia platforms, and 25% from colleagues.

Active Participants' Prior Knowledge: Pre-Test Results

The initial level of knowledge was measured with a 10-question pre-test in various formats (true/false, multiple choice, image descriptors, and matching items) covering basic cell biology concepts. Active participants achieved an average score of 8.3 out of 10, 14% of them scored below 6, 51% scored between 6 and 9, and more than 35% scored above 9 (see **Figure 6**). These results indicate that, while the topic is generally familiar, the majority of active participants do not merely need to review basic biology concepts; they are likely seeking clearer explanations and content that can be readily applied in the classrooms.

Intermediate Quizzes For Learning Self-Assessment

As previously described, the "QdC" MOOC was divided into three modules, each covering distinct topics. Active participants could follow the video lessons within each module at their own pace; however, it was important to ensure that the content of each module was understood before progressing. At the end of each module, a quiz assessing the covered material was administered. Completion of the quiz was required to proceed to the next module, with a minimum passing score of 6 out of 10. Active participants were allowed unlimited attempts.

An initial assessment of participant engagement can be made by comparing the proportion of active participants who completed the video lessons with those who passed the corresponding quizzes. As shown in **Table 2**, most active participants who watched the videos also passed the quizzes, indicating high engagement and comprehension.

Learning outcomes were further assessed quantitatively through three parameters: score distribution, average score, and average completion time (see **Figure 7**). Scores were interpreted using criterion-referenced categories: ≥ 80% = high mastery, 70-79% = satisfactory mastery, 60-69% = basic mastery, and < 60% = insufficient mastery. In **Figure 7**, active participants' scores are presented in terms of numeric grades (< 6, 6-6.9, 7-7.9, ≥ 8), which correspond to these mastery levels. The results show a consistent pattern across the three modules, with most active participants achieving scores in the satisfactory or high mastery categories, well above the minimum required.

The intermediate quizzes were mainly introduced to support the activation of self-assessment processes by active participants. Therefore, measuring the results of these quizzes was not essential in comparative terms but, given their nature, they were fundamental in supporting

Table 2. Video completion and quiz performance across modules

	Percentage of active participants who completed video lessons (%)	Percentage of active participants who passed the quiz (%)
Module 1	81	71
Module 2	67	63
Module 3	62	62

Note. Percentages are calculated based on N = 868 active participants who completed the pre-test and started the course

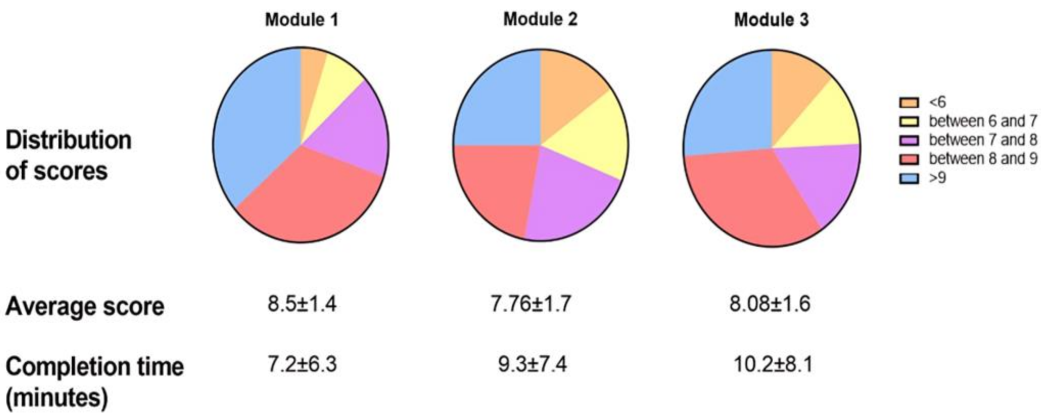

Figure 7. Quiz performance and completion time by module (Source: Authors' own elaboration)

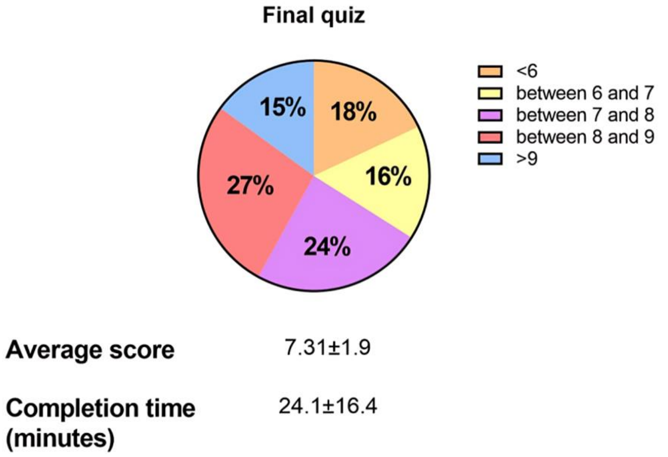

Figure 8. Final quiz performance and completion time (Source: Authors' own elaboration)

the sequential progress of active participants, stimulating reflection and metacognition (Boud & Falchikov, 1989; Ventista, 2018).

Final Test and Pre-Post Learning Outcomes

To obtain recognition for the course, active participants had to pass a mandatory final quiz, more complex than the intermediate quizzes. The final quiz consisted of 30 items in different formats (multiple-choice, true/false, sentence completion, and figure-definition matching), covering topics from all three modules. Each participant could attempt the quiz up to five times, and a score of 70% correct answers was required to pass.

As shown in **Figure 8**, most completers who attempted the quiz achieved very good results, falling within the high or satisfactory mastery categories, using the same criterion-referenced scale as for the intermediate quizzes. The mean score was 7.3. Completion time for the final quiz was higher than that of the intermediate quizzes (24 minutes vs. an average of 10 minutes), reflecting both the greater number of questions and the broader scope of the quiz. These data suggest that a large proportion of completers followed the course with genuine commitment and successfully consolidated their learning. The consistent achievement in the final quiz, coupled with sustained engagement throughout the course, suggests that the MOOC's design successfully fostered learner commitment. International studies indicate that structured pacing, modular design, and readily applicable classroom resources are critical factors that enhance engagement and reduce dropout rates in MOOCs for professional learning (Hew & Cheung, 2014; Kizilcec et al., 2017).

To support the interpretability of the observed learning outcomes, we examined the psychometric quality of the final assessment. While psychometric analyses were not applicable to all item types, multiple-choice and true/false questions were analyzed to assess their validity and reliability.

Internal consistency was evaluated for the nine dichotomous true/false items using the KR-20, yielding a reliability coefficient of KR-20 = 0.73. According to commonly accepted guidelines, a KR-20 value above 0.70 is considered acceptable for internal consistency in research instruments with dichotomous items, indicating that these quiz components have adequate reliability for the purposes of this study.

Furthermore, classical item analysis was conducted for the five multiple-choice items of the final quiz, evaluating item difficulty and discrimination. Item discrimination indices, computed using Kelley's method, ranged from 0.35 to 0.84, indicating good to very good discrimination power. Item difficulty indices ranged from 0.59 to 0.87, suggesting that the items were generally of moderate difficulty.

Together, these analyses indicate that the final assessment exhibited satisfactory measurement quality, providing methodological support for the interpretation of the learning outcomes reported above. Detailed item statistics are reported in **Table 3**.

Another fundamental aspect of the study is the actual acquisition of scientific content. To assess this, a pre-post comparison was conducted. The pre-test, designed to evaluate prior knowledge, was intentionally easier so as not to discourage active participants, whereas the final test was substantially more demanding and directly aligned with the course content. Despite these intrinsic differences, a comparison of pre- and post-test scores provides meaningful insights into completers' learning gains.

The main analysis on the full sample (N = 535) did not show a statistically significant improvement between pre- and post-test scores (paired t-test, two-tailed, $p = 0.17$). To quantify the impact, Cohen's d was calculated for the paired differences (post-pre), yielding $d = -0.06$, likely reflecting a ceiling effect: participants with high pre-test scores had limited room for

Table 3. Psychometric analysis of the final quiz

Item format	KR-20	Difficulty (p)	Discrimination (D, Kelley)	Interpretation
True/false (9 questions)	0.73	-	-	Acceptable
Multiple choice (Q9)	-	0.87	0.35	Slightly easy, good discrimination
Multiple choice (Q13)	-	0.75	0.59	Moderate difficulty, very good discrimination
Multiple choice (Q14)	-	0.79	0.51	Moderate difficulty, very good discrimination
Multiple choice (Q17)	-	0.59	0.84	Moderate difficulty, excellent discrimination
Multiple choice (Q20)	-	0.68	0.72	Moderate difficulty, excellent discrimination

improvement. Similar findings have been reported in other MOOC studies, indicating that learning gains are often more pronounced among participants with lower baseline knowledge, while higher-performing completers may show benefits not captured by standardized pre-/post-tests, such as enhanced confidence or teaching strategies (Gašević et al., 2014; Janelli & Lipnevich, 2021).

An analysis of individual performance changes revealed a non-symmetric distribution of score differences (post-pre), with larger positive gains and fewer negative changes, indicating that most completers improved their performance after completing the MOOC, though the magnitude varied depending on prior knowledge, engagement, or learning pace (see **Figure A1** in **Appendix A**). To investigate the effect of the course on completers with lower initial performance, secondary analyses were conducted on two subgroups defined a priori based on pre-test scores: completers scoring ≤ 6 (corresponding to sufficient or lower performance, N = 61) and those scoring ≤ 7 (including both low and medium-level performers, N = 114). For both subgroups, Δ = post-pre was calculated for each participant, and a one-tailed paired t-test was performed to assess whether the mean improvement was significantly greater than zero. Both subgroups showed highly significant improvements ($p < 0.001$), indicating that the course was particularly effective for completers with low or medium-low initial scores. These findings emphasize the importance of inclusive course design: providing resources that accommodate diverse prior knowledge levels can support more equitable learning outcomes, enhancing both engagement and the practical transfer of knowledge to classroom practice (CAST, 1998; Piroi et al., 2023).

Completers' Feedback and Satisfaction

Regarding overall participant satisfaction with the MOOC and following the approach adopted in previous studies on biology teachers' continuing professional development (Tzovla et al., 2021a), as mentioned in the methodology section, a questionnaire was developed specifically for the completers. The mandatory questionnaire consisted of three parts:

(1) general questions, similar to those in the initial questionnaire, to assess any differences between participant categories,

(2) overall satisfaction, with some parameters on a Likert scale from 1 to 6, and

(3) motivations for taking the MOOC.

Due to data anonymization, individual responses could not be linked to participant categories. Therefore, it was not possible to perform group comparisons (e.g., teachers vs. students or primary vs. middle school teachers) or to correlate motivation, engagement, and completion. A total of 535 completers (49% of course enrollees) completed the final questionnaire.

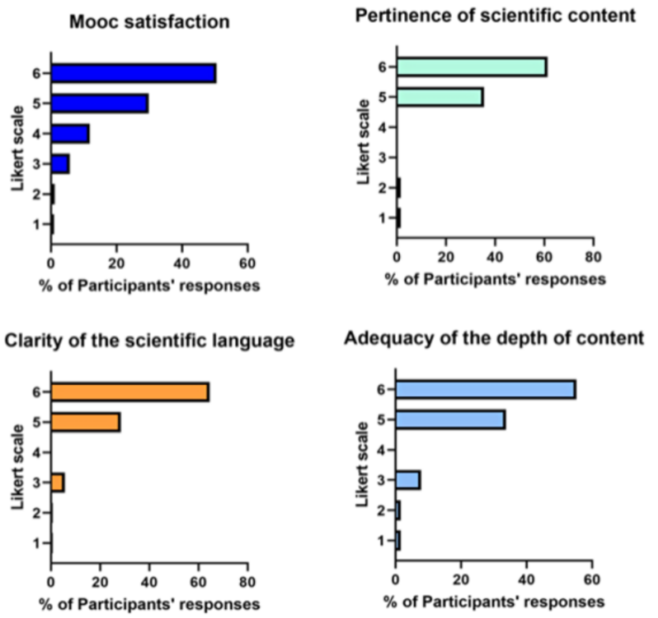

Figure 9. Overall feedback of MOOC's completers on a Likert scale from 1 to 6, where 1 indicates "not at all satisfied" and 6 indicates "extremely satisfied" (Source: Authors' own elaboration)

The demographic composition of course completers closely mirrored that of initial active participants, both in terms of geographical distribution and occupational background. This consistency suggests that the MOOC's content and structure were equally engaging and accessible across all participant categories, leading to a uniform completion rate regardless of completers' location or professional role (**Figure A2** in **Appendix A**).

The satisfaction with the MOOC was evaluated both in terms of the scientific content itself and its presentation, as well as the format used. Overall, the level of satisfaction was very high. More specifically, the scientific content was evaluated in terms of the appropriateness of the proposed topics, the level of detail, and the clarity of presentation and language. All parameters received highly positive feedback (see **Figure 9** and **Table A2** in **Appendix A**), confirming the soundness of the choices made during the design phase.

Internal consistency of the survey items measuring satisfaction was evaluated using Cronbach's alpha. The seven Likert-scale items (1-6) exhibited excellent reliability ($\alpha = 0.922$), indicating that the items coherently captured completers' perceptions of the course. The results obtained are consistent with findings from comparable MOOC implementations in teacher education. For example, in a similar study involving primary school teachers' professional development in biology, reported satisfaction levels were uniformly high, with mean scores ranging between 4.30 and 4.72 on a 5-point Likert scale (Tzovla, 2021b). The alignment between these findings and the present results further

Table 4. Data analysis about overall satisfaction of the MOOC's completers (535 answers) on a Likert scale from 1 to 6 (1-not at all to 6-extremely)

Overall appreciation	M	SD
Is the course format (recorded video lessons with animations and graphics) suitable for your needs?	5.3	0.9
Have the additional resources been helpful?	5.3	1.0
Do you think the forum is a useful tool for your activity?	4.3	1.5

Note. M: Mean & SD: Standard deviation

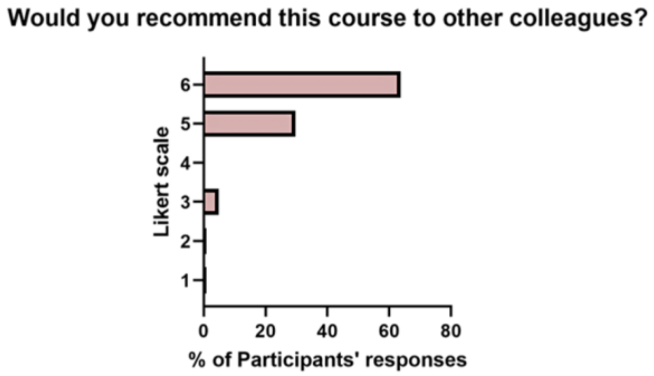

Figure 10. Percentage of MOOC completers' responses to the question 'Would you recommend this course to other colleagues?" on a Likert scale from 1 to 6, where 1 indicates "not at all" and 6 indicates "undoubtedly" (Source: Authors' own elaboration)

supports the effectiveness of the proposed MOOC design.

Regarding the structure, completers were asked to evaluate the various features of the MOOC (videos, additional resources, and the forum). The chosen format (short video lessons accompanied by supplementary materials) was undoubtedly successful (see **Table 4**), while the forum was slightly less appreciated.

As Conole (2014) affirmed, even if effective online learning was enhanced through dialogue and creativity, collaborative practices, reflective activities, the application of theory to practice, and peer motivation within an online community, the completers used the forum mainly to exchange and ask information about technical issue in relation to MOOC general participation, unless use it as a way to communicate and doubts, pose doubts, questions and share meaningful experiences. A qualitative review of forum activity revealed that the forum was primarily used for functional and support-oriented communication rather than for pedagogical discussion. As noted by Almatrafi et al. (2018), variation in the proportion of active participants can be partially attributed to differences in course design (e.g., mandatory vs. optional forum participation), the platforms employed, and the methods used to calculate participation rates (such as total enrolment vs. actual course access). In line with prior research, only a small proportion of learners—typically ranging from 5% to 25%—actively contribute to forum discussions (Huang et al., 2014; Oleksandra & Shane, 2016; Rosé et al., 2015; Sharif & Magrill, 2015; Tomkin & Charlevoix, 2014). Crucially, low levels of visible participation should not be equated with disengagement, as many learners engage with forums in a passive or observational manner. Supporting this view, Mustafaraj and Bu (2015) found that for each active participant there are approximately two passive learners, underscoring the legitimacy of "lurking" as a meaningful form of engagement in online learning environments.

A high percentage of completers (93.4%) stated they would recommend the course to a colleague (see **Figure 10**). Completers' strong willingness to recommend the course to colleagues provides converging quantitative evidence of the perceived value and effectiveness of the MOOC.

Another important aspect is the motivations driving completers to enroll in the MOOC. The majority (40%) stated they wanted to update their knowledge, while 26% sought materials for their classroom lessons. Interestingly, 20% of completers enrolled out of curiosity, and 13% cited other reasons. This indicates that the course content is appealing not only to teachers but also to a wider audience interested in cellular biology, reflecting its broader educational relevance.

In addition to specific questions, completers were given the opportunity to freely share their experiences and provide suggestions or advice. All the comments are very positive and constructive; the authors have carefully considered them for the development of a new edition of the course. A selection of these comments can be found in **Table A3** and **Table A4** in **Appendix A**.

Anyone who has completed the course can download the video lessons and use them offline by submitting a justified request to the authors. This option, not frequently offered in MOOCs, was available to facilitate specific educational purposes and to overcome the problem of inadequate Internet connections, often encountered in Italian school buildings. More than 140 completers have made this request. One participant who was granted permission to download the videos highlighted the pedagogical value of the materials, noting that access would significantly enhance the participant's teaching approach and benefit the participant's students.

Analysis of the Data Collected During the Focus Group

Mid-February 2024 saw an online meeting organized via the Zoom platform, to which all the active participants of the MOOC were invited. A total of 13

Figure 11. Word cloud built with focus group participants' responses to the specific question "how would you define the "QdC" MOOC in one word?" (Source: Authors' own elaboration)

Table 5. Answers to the question "What would you add to each module to facilitate the transfer of content to the children?"

Resources	n	Percentage (%)
Glossary	3	42.86
Graphical sum-up	1	14.29
Concept maps on the subject	5	71.43
Quizzes for students	3	42.86
Video slides	4	57.14
Subtitles to videos	2	28.57
other	0	0.00
Timelines	1	14.29
Infographics	2	28.57

Note. n: Number of votes

participants attended the meeting. The meeting was conducted as a focus group, employing a series of structured questions that guided the conversation, lasting 1 hour and 30 minutes.

Participants defined the MOOC as highly useful, interesting, professionally relevant and really important for teaching and learning process, stimulating, flexible, rich and in general "fantastic" (see word cloud collected during the focus group in **Figure 11**). Positive perceptions of flexibility and usefulness are consistent with studies highlighting MOOCs as effective tools for teacher professional development when perceived as relevant and applicable (Koukis & Jimoyiannis, 2017).

In terms of participants' appreciation of the MOOC's structure, the attendees highlighted that the most important and useful resources were the MOOC's videos themselves (score 5, on a Likert scale 1-5), followed by the historical insights (4.8), infographics (4.8), scientific insights (4.7), activity sheets to propose in class (4.7), quizzes (4.3) and specific videos for primary school (4.1). The strong appreciation for short and usable videos aligns with multimedia learning research, which shows that well-segmented audiovisual materials enhance engagement and reduce cognitive load (Mayer, 2009).

The information related to the specific question "What would you add to each module to facilitate the transfer of content to the students?" is possible to be seen in **Table 5**.

These data are also highlighted during the discussion: in fact, participants gave some suggestions for the general improvement of the course (7 quotations). For example, teachers suggest adding static slides to accompany the videos to facilitate explanation and allow a slower, more assimilable learning pace for students (1:9). The need for complementary static materials reflects principles of cognitive load theory, according to which pacing and multimodal support facilitate processing (Mayer, 2009).

Other suggestions are connected to the visibility and the usability of the MOOC's resources: for example, participants highlight the need for additional teaching materials to support learning in the classroom, especially for students with different learning rhythms (1:11), but they express also the need to deepen focus specific words in videos (1:28) and the implementation of specific explanatory videos and experimental practices to share with colleagues (1:30). This emphasis on classroom-ready resources is coherent with research on effective teacher professional development, which stresses practical applicability and transfer to practice (Desimone, 2009).

Another important aspect to be evaluated is the inclusiveness of the course, particularly with a view to planning a second edition; therefore, specific questions and related discussion are dedicated to students with special learning needs. For the question "What would you add to each module to facilitate the transfer of content also to students with special learning needs?," participants shared some suggestions with particular focus on the specific students target (6 quotations). For example, they suggested that the addition of static materials such as slides could also be useful to facilitate the learning of students with special educational needs (1:10). In addition, they introduced the possibility to adopt audio of texts for visually impaired students (1:32), video with practical explanations and visual demonstrations (1:34), interactive glossaries with explanations of key terms (1:35) and in general simplified teaching materials and summaries to facilitate understanding (1:36).

The crucial elements that emerged are listed in **Table 6**.

In relation to the practical use of the MOOC's resources (What kind of resources from the course did you use/do you intend to use in class?), teachers reported the use of audio of texts for visually impaired students (1:16) and concept maps to aid understanding, especially for students with dyslexia (1:17), so really connected to a universal design for learning approach (CAST, 1998).

In terms of general perception of the MOOC, first of all the videos were considered engaging, short and

Table 6. Answers to the question "What would you add to each module to facilitate the transfer of content also to students with special learning needs?"

Choices	n	Percentage (%)
Videos' slide	2	25.0
Concept maps	6	75.0
Audio of videos' texts	2	25.0
Picture/images and flash cards	5	62.5

Note. n: Number of votes

usable, facilitating integration into teachers' routines (1:4). The contents were very much related to the current context and useful to stimulate students' interest (1:5).

Some participants mentioned the thoroughness of the videos and their usefulness in class activities (1:13) and MOOCs resources were defined as versatile resources that can be used in different educational contexts (1:20). Furthermore, the overall practical approach supported and facilitated active learning (1:21), which aligns with research showing that active and practice-oriented approaches are central elements of effective teacher professional development (Darling-Hammond et al., 2017).

As weaknesses of the MOOC, focus group participants suggested slowing down the videos, in order to improve the enjoyment of the learning experience (1:7). It could be also useful to introduce the possibility of adapting the contents for the use with students with linguistic differences (1:24), in line with the universal design for learning principles (CAST, 1998) and previous MOOC studies targeting inclusive classroom practices (Piroi et al, 2023).

Finally, the analysis highlighted difficulties in cultivating an online community to share practices and support peer learning (1:26), which is consistent with research showing that MOOCs often struggle to establish sustained social presence and collaborative engagement among participants (Kirschner & Lai, 2007; Koukis & Jimoyiannis, 2017).

Feedback Module on Proposed In-Class Activities and on New Materials to Include For the New Version of "QdC"

At the end of February 2024, all "QdC" active participants were invited to respond to a Google Form, partly proposed during the focus group, to understand in more detail whether and which of the proposed in-class activities had been used and/or found useful. A total of 37 active participants completed the form, providing preliminary insights into classroom implementation. Although collected shortly after course completion, these data offer an initial indication of the MOOC's sustained usefulness, showing whether teachers are able to implement newly learned practices in their own classrooms. Although based on a limited subsample, these data provide an important indication of behavioral-level impact, corresponding to higher levels of professional development evaluation frameworks, where changes in teaching practice represent a key outcome beyond satisfaction or knowledge acquisition (Desimone, 2009; Kirkpatrick, 1998). The form asked which resources could be useful to add (videos, glossaries, concept maps, quizzes for students, or video subtitles), including those for students with special educational needs.

Respondents stated that during their classes they implemented the use of videos (75%), followed by practical laboratory activity sheets (27.8%), scientific insights (13.9%), infographics (2.8%) and historical insights (2.8%). This indicates a strong preference for video-based content, while more interactive or supplementary materials are less frequently adopted, suggesting potential areas for enhancement. The fact that teachers actively applied these materials in their classrooms demonstrates that the course has practical and ongoing value for professional development.

In response to the question "What resources would you add to each module to facilitate the transfer of content to your students?" respondents answered as follows: 55.6% said they would need quizzes to administer to students, 41.7% requested concept maps, 22.2% asked for slides containing the video content (see **Figure 12**). The discrepancy between current usage (high video adoption) and requested resources (quizzes, concept maps) highlights a gap between passive content delivery and tools that support active learning and knowledge consolidation. Research shows that integrating active learning strategies into instructional videos enhances comprehension, retention, and transfer compared to passive viewing alone, while tools such as concept maps promote deeper cognitive organization and improved learning outcomes (Amante et al., 2026; Zhang et al., 2025).

The form also proposed specific questions about students with special learning needs. The researchers asked respondents whether they have ever had experience with students with specific learning needs and what types of learning needs they have encountered. The results are visible below in **Figure 13**. In connection with that question, respondents were asked to identify specific elements that they would like to add to each module in order to facilitate the contents' use for students with special learning needs. They suggest adding conceptual maps (56.8%), but also pictures and flashcards (43.2%), slides connected to the videos (16.2%) and audio connected to the texts and videos (8.1%). These responses demonstrate an explicit concern for inclusive practice, indicating that teachers perceive the MOOC not only as a source of disciplinary knowledge but also as a resource base to support differentiated instruction. The emphasis on visual, multimodal, and scaffolded materials aligns with universal design for learning principles, which stress multiple means of

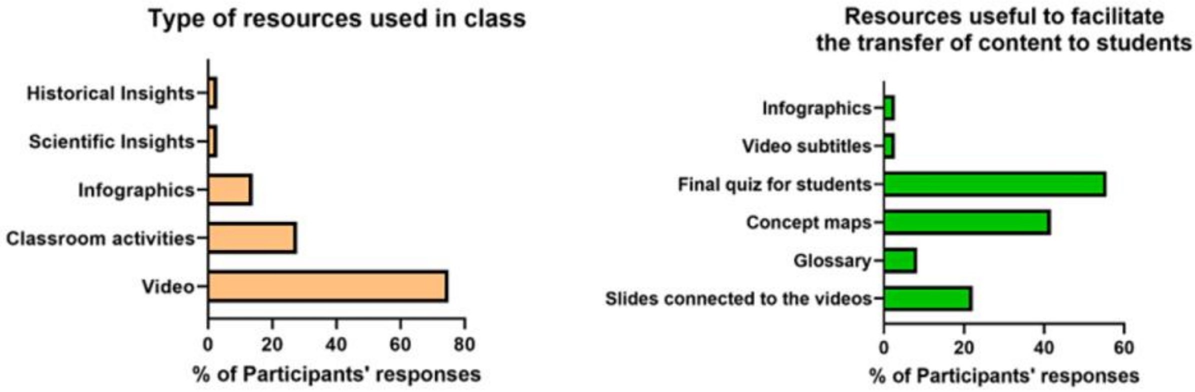

Figure 12. Percentage of responses provided by MOOC course respondents to the question "What type of resources from the course have you used in your classroom?" and "What resources would you add to each module to facilitate the transfer of content to your students?" (Source: Authors' own elaboration)

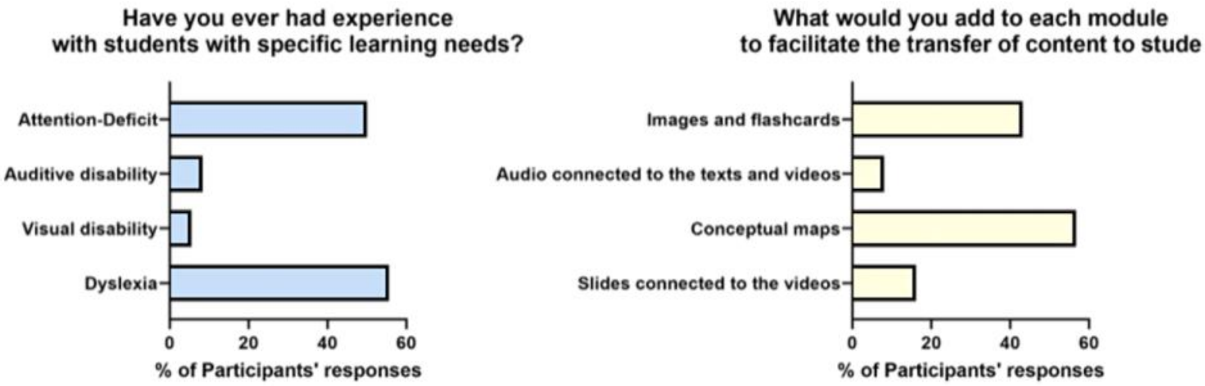

Figure 13. Percentage of MOOC active participants' responses to the questions "Have you ever had experience with students with specific learning needs?" and "What would you add to each module to facilitate the transfer of content to students with special educational needs?" (Source: Authors' own elaboration)

representation and access to content (CAST, 1998). This feedback underscores the importance of inclusive design: active participants who work with students with special needs prioritize visual and multimodal resources, suggesting that future iterations of the MOOC should integrate these materials to enhance accessibility and learning outcomes for all students. Additionally, the higher demand for conceptual maps and visual aids reflects a need for structured supports that scaffold student understanding (Amante et al., 2026; Zhang et al., 2025).

The literature does not provide enough scientific contributions comparable to the research protocol adopted. After a thorough review, few studies emerged that examined continuing professional development processes for biology teachers through a MOOC. The studies examined either consider different targets (Brouwer et al., 2022), carry out different analyses in terms of impact on respondents (Tzovla et al., 2021a), or adopt general approaches to exploring the effects of these programs, without a specific connection to a reference discipline (Tzovla et al., 2021b).

Overall, these responses indicate that while current in-class activities are partially implemented, there is a clear demand for additional structured resources, particularly quizzes, concept maps, and multimodal support for students with special educational needs. By addressing the discrepancy between materials currently used and those requested by teachers, future iterations of the MOOC can further strengthen its long-term impact and continued usefulness in supporting classroom practice. Incorporating these elements in the next iteration of the course could enhance engagement, facilitate content transfer, and support inclusive teaching practices.

CONCLUSION

The "QdC" MOOC, specifically designed for primary and middle school science teachers in Italy, has demonstrated significant success and filled a crucial gap in teacher training. With a high completion rate of 49% (535 out of 1,100 enrollees), the course attracted a mix of in-service teachers, pre-service teachers, and undergraduate students, predominantly from Northern Italy (66%), with 40% from the Veneto region (where the University of Padua is located).

From a learning perspective, the course supported knowledge consolidation and reflective engagement. The absence of a statistically significant overall pre-post improvement can be interpreted in light of participants' highly variable prior knowledge, which limited measurable growth for those already performing at a high level. At the same time, individual results show that many participants improved, while those with higher initial scores had limited room for further measurable gains. This indicates that the MOOC's impact varied depending on prior knowledge rather than being uniform across all participants (Janelli & Lipnevich, 2021). In this framework, the intermediate quizzes functioned primarily as formative tools, fostering self-assessment and metacognitive processes throughout the learning pathway (Boud & Falchikov, 1989; Ventista, 2018).

Completers reported high satisfaction both with the delivery model and with the quality of the content. The asynchronous format was perceived as particularly compatible with teachers' professional needs, while the scientific rigor, clarity, and depth of the materials were consistently rated very positively. These findings indicate that the MOOC model adopted is pedagogically appropriate for this target group.

Insights from the focus group complemented the quantitative findings by confirming the MOOC's strong perceived usefulness and the central role of videos and ready-to-use teaching materials in supporting classroom practice. Completers emphasized the need for additional structured resources such as concept maps, slides, and multimodal tools to facilitate content transfer and inclusivity. At the same time, discussions highlighted persistent difficulties in fostering peer interaction, indicating that strengthening community-building strategies remains a key area for future development.

With regard to the assessment of the impact of the content learned on teachers' actual practice, given the low response rate to the questionnaire about the use of the proposed classroom activities, it was not possible to ascertain the real change made by those who used the MOOC content. Consequently, the assessment was carried out mainly on the levels of satisfaction and learning, while the levels relating to behavioural change and the connected impact on educational processes were not investigated directly (Kirkpatrick, 1998). This aspect could represent a possible future line of research linked to the project developed.

A methodological limitation of this study is the partial misalignment between the intended target group and the actual participant population (as also reported by Milligan & Littlejohn, 2017). While the MOOC was designed for in-service primary and middle school teachers, a substantial proportion of active participants consisted of university students and pre-service teachers. Consequently, the findings should be interpreted as reflecting the overall participant experience rather than being generalized exclusively to practicing teachers. Notably, the presence of university students and pre-service teachers may be viewed as an added value of the initiative, as these active participants are likely to become future teachers and thus represent a relevant target group for early professional development. It's also important to note that the forum provided within the MOOC saw low levels of engagement. The goal of creating an online community for mutual exchange, sharing of best practices, and educational experiences was not fully realized. This suggests that it is important to enhance this MOOC aspect, trying to understand how to better foster the communication process between participants, maybe implementing in-person or online synchronous meetings. In this way, teachers could find a deeper connection with peers, improving the possibility of sharing experiences and best practices through an informal approach in a formal learning environment (Kirschner & Lai, 2007).

Despite some limitations, overall feedback confirms the "QdC" MOOC as an effective and accessible model for science teacher professional development across a diverse participant population, in line with previous studies on MOOCs for teacher continuous professional development (Tzovla et al., 2021b). The findings presented in this paper derive from a specific national contest, yet they can make a significant contribution to the international discussion on MOOCs in teacher professional development. Our data show that discipline-specific xMOOCs can serve as structured tools for large-scale professional learning, supporting not only content acquisition but also the translation of complex scientific knowledge into classroom practice. Building on completers' suggestions, future iterations will include video subtitles, full transcripts, downloadable slides, concept maps, quizzes, and strategies to enhance online community engagement. The "QdC" MOOC represents a valuable and innovative contribution to teacher training in Italy, bridging the gap between traditional in-person training and the growing demand for flexible, online professional development opportunities.

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Ethical statement: The authors stated that the study does not require any ethical approval. The study involved the analysis of anonymized, aggregated data from a Massive Open Online Course (MOOC). The data used in this research consisted of demographic information (region of origin in Italy, age, and occupation) and learning assessment results, all of which were collected as part of the standard MOOC registration and participation process. The authors further stated that no personally identifiable information was accessed or used in the analysis. This type of secondary analysis of anonymized, pre-existing educational data is generally considered exempt from ethical review according to most

institutional and national guidelines for research involving human participants.

AI statement: The authors stated they used ChatGPT for language editing during manuscript preparation. The authors reviewed all content and take responsibility for the accuracy and integrity of the work.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: DESIGNING A MOOC FOR PRIMARY AND MIDDLE SCHOOL SCIENCE TEACHERS

Table A1. Resources for each module of the "QdC" MOOC

Module	Resource type	Title/description
Module 1. Cells as the basic units of living organisms	In-depth resource	Chemistry Matters–introduction to chemical components of cells and their role in life processes.
	Infographic	Cell sizes–comparison of sizes of different cell types.
	In-depth resource	Colorful cells–guide on observing stained cells under a microscope.
	In-depth resource	How to observe cells under a microscope–practical guide for classroom microscopy experiments.
	Classroom activity	Cell building, cell puzzles, cells as a city, cells and mind maps–hands-on activities for exploring cell structure.
	Video	2 short videos for primary school students–introducing cell concepts in an age-appropriate way.
Module 2. Cellular reproduction	Historical insight	Friederich Miescher, the man who discovered DNA–story of the scientist who identified nucleic acids.
	Historical insight	Rosalind Franklin, the story of a great injustice–biography and contribution to DNA structure discovery.
	In-depth resource	Cells and recycling–explanation of cellular recycling mechanisms.
	Historical insight	Gregor Mendel: The monk with a passion for gardening–introduction to genetics foundations.
	In-depth resource	Imperfect DNA: genetic pathologies–overview of genetic disorders.
	In-depth resource	Brothers, sisters, twins–discussion on monozygotic and heterozygotic twins.
Module 3. How cells communicate and specialized cells	In-depth resource	Talking about viruses–explanation of viruses and how they interact with cells.
	Historical insight	The story of the first vaccine–history of vaccine development.
	Timeline	The pioneers of vaccines–timeline of important figures in immunology.
	Infographic	2 infographics about vaccines and viruses–visual explanation of virus structure and vaccine mechanisms.
	In-depth resource	2 resources on cell study techniques and HeLa cells–deeper exploration of experimental approaches.
	Historical insight	Rita Levi-Montalcini–biography highlighting her contributions to neuroscience and cell biology.
	Classroom activity	How to build a cytology atlas, cell memory game–interactive activities to reinforce cell knowledge.

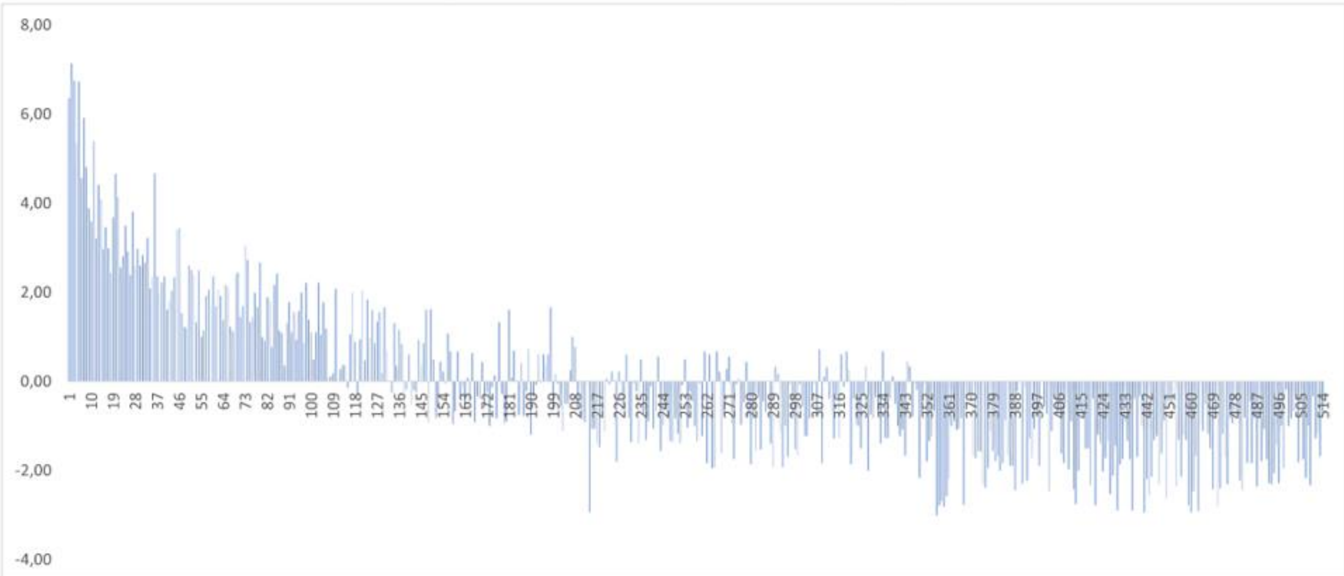

Figure A1. Distribution of individual score differences (post-pre) showing learning gain (Source: Authors' own elaboration)

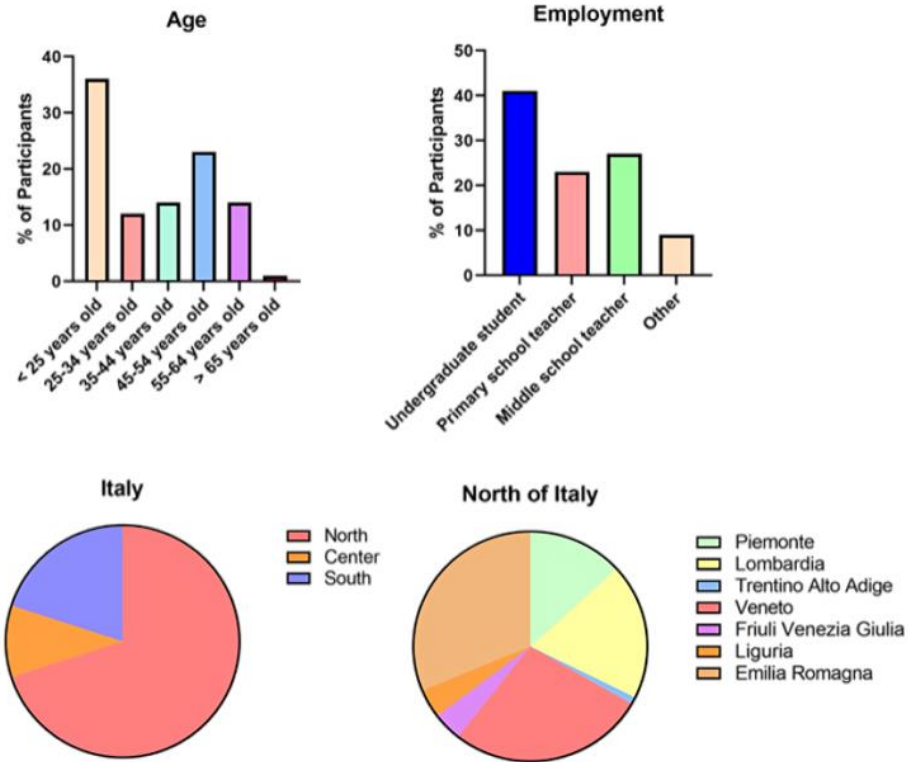

Figure A2. Data on participants who completed the course (N = 535) (Source: Authors' own elaboration)

Table A2. Data analysis about overall satisfaction of the MOOC's participants (N = 535) on a Likert scale from 1 to 6 (1-not at all to 6-extremely)

Overall appreciation	Mean	Standard deviation
Are the scientific contents presented adequate?	5.2	1.0
Is the level of depth appropriate?	5.1	1.1
Is the language used clear and understandable enough	5.4	0.9

Table A3. Selected open-ended comments from MOOC completers (these excerpts are illustrative examples from the open-ended feedback responses and are provided to contextualize completers' perceptions of the course experience)

ID	Completer comment
C1	If you want to take a course to get more information, 'cell matters' is the right one!
C2	I suggest continuing with this teaching method. For example, the videos explain very well and make the acquisition of information easy
C3	I believe the work done is enjoyable, engaging, and rich in coherent and relevant scientific information. I extend my sincere compliments to the staff in charge of direction and production.
C4	Course useful for my training. Clear videos and appropriate analogies to understand.
C5	The course is useful and clear. The online mode is perfect for managing the course according to one's commitments
C6	The course was truly interesting and well-structured. Congratulations!
C7	I really enjoyed the format of this course, never boring and rich in information, keeping attention high. The downloadable resources were very useful for obtaining innovative and creative material for classroom lessons. Thank you!
C8	The videos are very well done: Perfectly suited for middle school students. Short and clear, they cover the main aspects of the topics.
C9	The materials are presented in a very well-crafted and engaging manner, also offering useful teaching insights for primary school children.
C10	The classroom activities are very interesting ... I will definitely propose to my students!

Table A4. Selected suggestions from open-ended feedback provided by MOOC completers (these excerpts illustrate completers' proposals for course improvement)

ID	Completer suggestion
S1	Being able to re-share the operational experience, once implemented in the classroom
S2	A glossary suitable for primary school on cells would be useful.
S3	More exercises/practice activities, or quizzes.
S4	Ideas for simple laboratory activities easily implementable in middle school, using readily available and low-cost materials.
S5	Dividing the course between primary and middle school levels.
S6	Adding videos about simple routine operations performed in research laboratories
S7	Offering additional lessons.
S8	Replacing the forum with live online meetings at the beginning and end of the course for introductions, questions, and idea exchange.

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