HECOF
Higher Education Classroom Of the Future

Higher Education Classroom Of the Future

D3.2 Learning Design Document for HECOF's POLIMI pilot class

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Executive Summary

The HECOF initiative aims to revolutionize higher education teaching practices and education policies by creating a personalized and adaptive learning system that utilizes digital data from students' immersive learning experiences and leverages computational analysis from data science and AI. The project will focus on the field of Chemical Engineering and involve teachers and students from two pilot universities in its design and implementation.

This report is part of the deliverables from a project called "HECOF" which has received funding from the European Union’s ERASMUS+ research and innovation program under grant agreement No 101086100.

The present document presents the Learning Design Document for POLIMI pilot class. It details the learning objectives of the course for the POLIMI pilot class, provide an overview of the curriculum mode underlying the POLIMI pilot class, present the learning loops design of the POLIMI pilot class and how content was reorganized to enable an AI-based adaptive learning experience. The document should give any reader a non-technical understanding on how the learning experience will look like for students and how the AI Adaptive Learning Engine should adapt and personalize the learning experience. The document also serves as input to the configuration of the Adaptemy AI Adaptive Learning Engine for the HECOF System.

Abbreviations and acronyms

Abbreviation	Definition
Abbreviation	**Definition**
HEI	Higher Education Institutions
AI	Artificial Intelligence
VR	Virtual Reality
VET	Vocational education and training
LLM	Large Language Model

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1. Introduction

1.1 About the project

Higher Education Classroom Of the Future (HECOF) project is implemented by a mixed partnership of organisations from different sectors that have the capacity to innovate in terms of digital tools and teaching and learning methods for the higher education systems, by leveraging the power of AI and machine learning for student assessment and adaptive learning based on individual learner's performance and behaviour. The main goal of the HECOF initiative is to create systemic change in higher education teaching practice and national reforms in education by developing and testing an innovative personalised, adaptive way of teaching that exploit the digital data from students' learning activity in immersive environments and use computational analysis techniques from data science and AI. The project has a conceptual focus on "Chemical Engineering" academic discipline and will engage teaching staff and students from two pilot universities in its design and pilot testing. HECOF also wants to foster the development and uptake of safe and lawful AI that respects fundamental rights by providing insights on ethical and legal issues around the design of the system. It will drive the policy agenda by formulating recommendations on the role and use of AI for personalised, adaptive learning HECOF technology has a clear potential to be mainstreamed in vocational education and training sector for employees in chemical engineering sector. Therefore, HECOF will support the first strategic priority of the Digital Education Action Plan (2021-2027), the development of a high-performing digital education ecosystem, by building capacity and critical understanding in all type of education and training institutions on how to exploit the opportunities offered by digital technologies for teaching and learning at all levels and for all sectors and to develop and implement digital transformation plans of educational institutions.

1.2 Overall Objective

The primary goal of the HECOF project is to drive systemic change in higher education by promoting innovation in teaching practices and national education reforms. This will be achieved by developing and testing an innovative, personalized, and adaptive approach to teaching that utilizes digital data from students' learning activities in immersive environments and incorporates computational analysis techniques from data science and AI.

1.3 Specific Objectives in WP3

1) Revision of the learning objectives and the tasks students need to complete to achieve that learning objective within the Chemical Engineering pilot classes.
2) Definition of the scenarios design and instructional activities to enable the effective utilization of the HECOF system capabilities to support the desired learning outcomes.
3) Definition of the conceptual assessment framework and instructional strategy
4) Content curation from existing teaching resources

1.4 Purpose of the document

D3.2 presents the Learning Design Document for POLIMI pilot class. It details the learning objectives of the course for the POLIMI pilot class, an overview of the curriculum mode underlying the POLIMI pilot class, the learning loops design of the POLIMI pilot class and how the content was reorganized to enable an AI-based adaptive learning experience.

The document gives any reader a non-technical understanding on how the learning experience will look like for students and how the AI Adaptive Learning Engine should adapt and personalize the learning experience.

It is important to note that it is not in the scope of this document to specify detailed design of the user interface or individual screens or any specifications of any algorithms or configurations to realise the Learning Loop recommendations. The document focuses on a breakdown of the overall student experience in terms of curriculum, content, and learning loops, including individual goals and rationales for the learning loops.

1.5 Approach taken in crafting the learning experience

Several activities were planned to craft the learning experience (see Figure 1). A series of online learning design workshops were created and the HECOF partners took part.

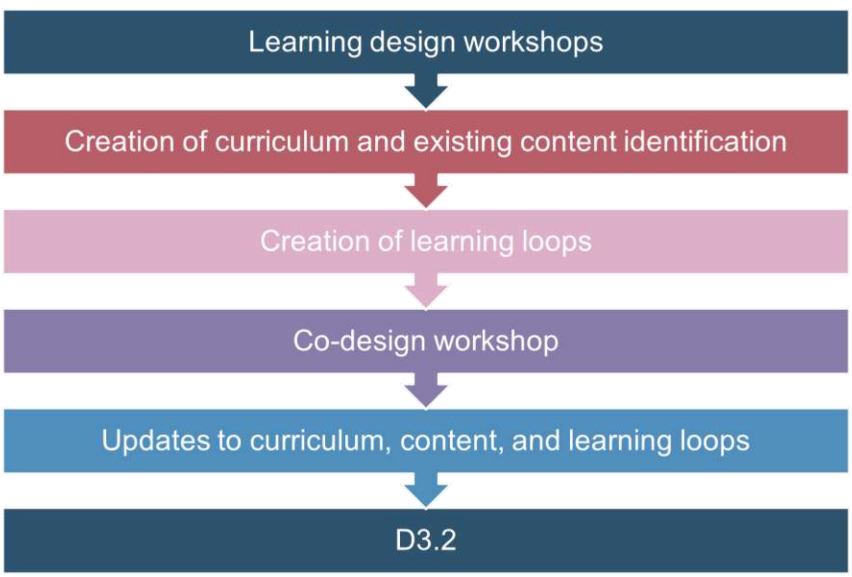

Figure 1. Overview of the approach taken in crafting the learning experience

The learning design workshops were organised for better understanding of

- how to structure content and curriculum for AI-based adaptive learning
- the domain (curriculum and content) in the pilot context
- the HECOF learning design vision
- the HECOF piloting
- the learning experience vision, role of the VR
- how to create the core learning design (NTUA, POLIMI)

The workshops were created by Adaptemy and included sessions to understand key AI-based Adaptive Learning and learning design concepts and to create initial versions of POLIMI Curriculum, content metadata and learning loops.

Then, offline tasks were taken to:

- Create the POLIMI curriculum, identify existing content
- Create the learning loops (details of the learning loops are presented in Chapter 3 of the document).

One co-design workshop for each pilot institution was organised. During the co-design workshop, special sessions were dedicated to AI-based Adaptive learning and Learning loops where the learning experiences were discussed with both lecturers and students.
Given the feedback from the co-design workshop, updates to curriculum, content and learning loops were made. D3.2 presents learning experiences for the POLOMI pilot class through the lenses of curriculum, content and learning loops. Full configuration of the AI-Adaptive Learning Engine for the Learning Loops will be made as part of the WP4.

2. Curriculum and Content

2.1 Curriculum Overview

A curriculum model[1] is a representation of "knowledge domain" and it is used to structure as an overlayer to the learning experiences provided to students. The curriculum model plays a crucial role in shaping the educational learning experience and outcomes for students, guiding an AI engine what students should master. Furthermore, the curriculum model is the overlay model for modelling mastery, being projected to the learner model.

Starting from the "learning objectives" or "learning outcomes" of a course, the teaching concepts (knowledge items) are created and encapsulated to a curriculum model for each course.

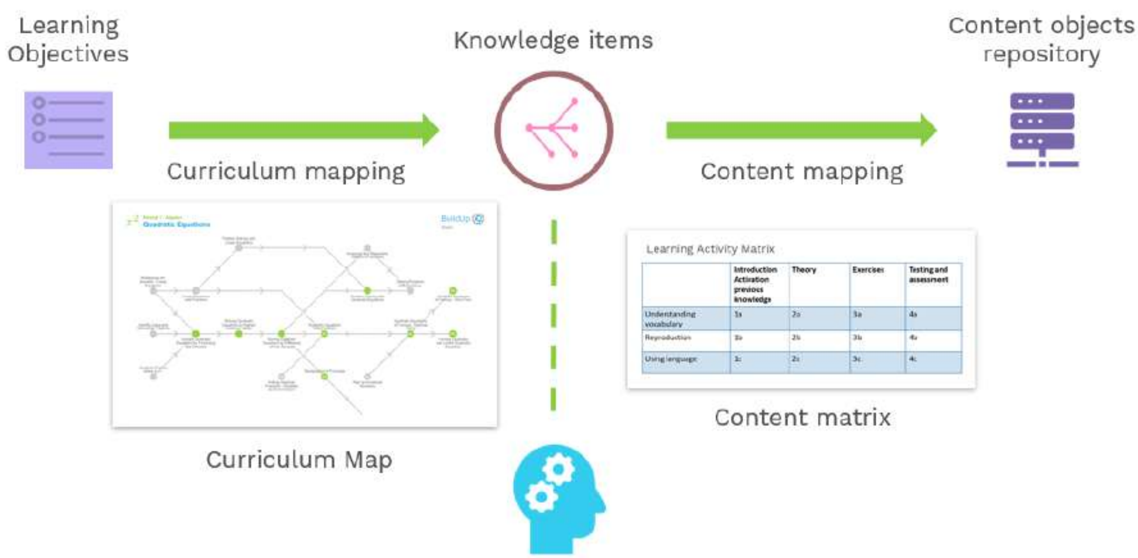

Figure 2. Schematic overview of curriculum and content mapping

The curriculum includes knowledge items (concepts) and their interrelationships, structured into two networks: a hierarchy network and a prerequisite network. The hierarchy network organizes curriculum content similarly to a textbook, aiding in navigation and assessment, while the prerequisite network defines the necessary prerequisites relationships between knowledge items. The prerequisite networks facilitate misconception detection and enabling multiple layers of personalization and adaptation in learning.

Looking at the benefits of creating a curriculum model, we can list the following:

- The curriculum facilitates the smart structuring and the creation of the educational content with at the correct level of granularity. This structured approach allows a learning system to personalize content recommendations for each student.

[1] https://www.adaptemy.com/how-do-you-update-the-curriculum-model-2

- The curriculum map facilitates the learning journey personalization, for example, when a student encounters difficulties, the curriculum map can be used to identify foundational and prerequisite concepts they may be missing.
- The curriculum map facilitates student modelling at the right granularity and further modelling through the Bayesian propagation.

2.2 POLIMI Pilot Course Learning objectives

The learning objectives for the POLIMI Pilot are presented in Table 2.

Table 1. Learning objectives for the POLIMI pilot course

Concept	Tag	Learning Outcomes
Fermentation processes and Biopharmaceuticals production	Intake	Students will understand what the term fermentation refers to and where it is applied. Students will be able to recognize the different classes of biopharmaceuticals and how they are produced.
Recombinant Technology	Knowledge acquisition	Students will be able to describe the principles of protein expression in host organisms and the technologies available for transfection with the required gene sequence
		Students will be able to identify the hurdles in the recombinant production of biotherapeutics and list pros and cons associated to the different microorganisms
Hybrid modelling of biological processes	Knowledge acquisition	Students will be able to describe the complexity of cellular metabolic pathways and to integrate statistical approaches for their mathematical description
		Students will be able to recognize the most important processes regulating the production of biopharmaceuticals and to schematize them mathematically
Fermentation bioreactors	Practising	Students will be able to formulate the key features of a fermentation bioreactor in the three different configurations of batch, fed-batch and chemostat through the application of material balances on the different components and on the cells
		Students will be able to estimate the productivity of the fermentation process in the three different configurations of batch, fed-batch and chemostat
Perfusion bioreactors	Practising (VR)	Students will be able to examine the advantages of perfusion cultures and the physical meaning as well as how to define the main process parameters

		By applying conservation equations, students will be able to predict the functioning of reactor and cell retention device

2.3 POLIMI Pilot curriculum

Based on the learning objective and course materials, the concepts (knowledge items) were extracted. For example, the following concepts were identified in the strand "Bioreactor Technology"

- Fermentation processes and Biopharmaceuticals production
    - Fermentation processes and Biopharmaceuticals production
- Recombinant Technology
    - History of recombinant technologies with the cornerstone discoveries that advanced the field
    - Processes for transfecting a cell and expand the substrate
- Hybrid modelling of biological processes
    - Mathematical description of the evolution of a cell population, highlighting the necessity of statistical approaches
- Fermentation bioreactors
    - Derivation of the most relevant conservative equations for a bioreactor
    - Analysis of the factors affecting productivity for the different reactor configurations
- Perfusion bioreactors
    - Key hardware elements to realize perfusion cultures
    - Derivation of the most relevant conservative equations for a perfusion bioreactor

Figure 3 presents the Hierarchy view of POLIMI Pilot curriculum in the Adaptemy Curriculum Authoring Tool while Figure 4 presents the Pre-requisite view of the POLIMI Pilot Curriculum in the Adaptemy Curriculum Authoring Tool.

The following Knowledge Items Type metadata was added to the concepts (see Figure 5):

- Intake
- Knowledge Acquisition
- Practising
- Practising VR

This metadata helps to better organize the knowledge items.

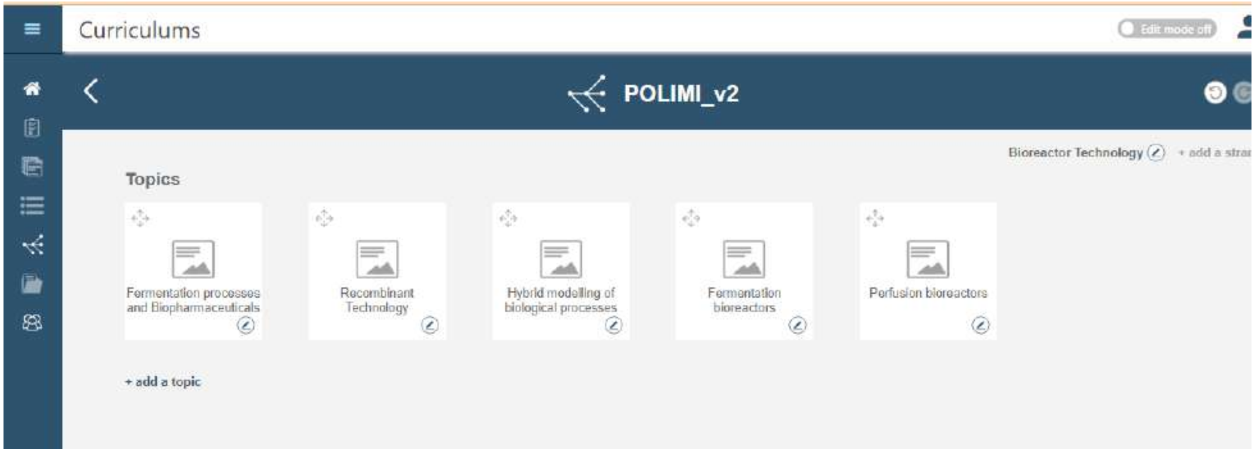

Figure 3. POLIMI Curriculum in the Adaptemy Curriculum Authoring Tool – Hierarchy view

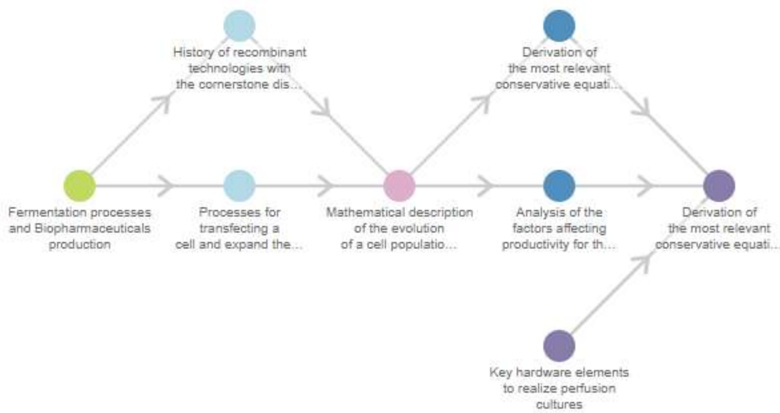

Figure 4. POLIMI Curriculum in the Adaptemy Curriculum Authoring Tool – Prerequisite view

Figure 5. Knowledge Items Metadata: "Type"

2.4 Content

2.4.1 Learning Activity Matrix

A Learning Activity Matrix [2] (LAM) is a metadata tagging framework that will be used to tag content and will be further use in learning loop creation. It contains the activities (or learning-phases) that will more likely form a sequence in the learning loop (i.e., Instructional-Assessment). LAM's primary

[2] Jiunn Huat Soo and Ioana Ghergulescu (2023), *Unboxing the Blackbox: Learnings from the ALS Pilot*, 15th International Conference on Education Technology and Computers (ICETC 2023)

purpose is to organize the content and illustrate the range of learning activities will be used. The matrix helps educators and instructional designers to ensure that a variety of learning experiences are provided to meet the diverse needs of learners. Additional metadata can be added to each learning phase.

Key characteristics of a Learning Activity Matrix include:

- **Alignment with Learning Loops**: Each activity in the matrix is typically aligned with specific learning states in the learning loop. This ensures that all activities are purposeful and contribute to the overall educational goals.
- **Diversity of Learning Experiences**: By laying out activities in a matrix format, educators can visually assess whether they are providing a diverse range of learning experiences. This diversity is important to cater to different learning styles and to keep students engaged.
- **Balance and Sequence**: The matrix can help in planning the sequence and balance of activities, ensuring an appropriate mix of different types of learning experiences throughout the course.
- **Assessment Integration**: Often, the matrix also integrates assessment strategies, linking them to both learning activities and objectives. This helps in creating a coherent and aligned assessment plan.

In practice, a Learning Activity Matrix might take the form of a table or grid, with each cell of the matrix then describes a specific activity that contributes to the corresponding learning experiences.

Figure 6. Learning Activity Matrix for the POLIMI pilot

In a learning experience, various content types play specific roles, each with its own rationale, contributing to an effective and comprehensive learning experience.
Figure 6 presents the Learning Activity Matrix for POLIMI pilot compose of type such as

- Instructional Content[3,4]
    - *Role*: This is the primary source of new information or skills for learners. It usually includes material that introduces and explains the subject matter.

[3] Castro, M. D. B., & Tumibay, G. M. (2021). A literature review: Efficacy of online learning courses for higher education institution using meta-analysis. *Education and Information Technologies*, *26*(2), 1367–1385. https://doi.org/10.1007/s10639-019-10027-z

[4] Fryirs, K. (2022). A pedagogy of fluvial geomorphology: Incorporating scaffolding and active learning into tertiary education courses. *Earth Surface Processes and Landforms*, *47*(7), 1671–1679. https://doi.org/10.1002/esp.5368

- *Rationale*: Instructional content is designed to convey the core knowledge and skills that learners are expected to acquire. It's structured to build on previous knowledge and to progress logically to more complex concepts.

- Assessment Item[5, 6, 7]
  - *Role*: Assessments, such as quizzes are used to evaluate the learner's understanding and mastery of the instructional content. They provide both the learner and the educator with feedback on progress and comprehension.
  - Rationale: Assessments are essential for measuring mastery on concepts and for identifying areas where learners might be struggling. They also reinforce learning by requiring learners to apply and reflect on what they have learned.
- Instructional Remediation[8, 9]
  - *Role*: This content is provided when assessment results indicate that a learner has not fully understood a concept or skill. Remediation can take the form of additional explanations and examples.
  - *Rationale*: The purpose of remediation is to address learning gaps and to provide learners with another opportunity to grasp the material fully. It's a personalized approach to ensure all learners reach the required level of understanding.
- Virtual Reality (VR) [10,11]
  - *Role*: In a learning experience, VR can be used to create immersive, interactive environments for practice, exploration, or simulation of real-world scenarios.
  - *Rationale*: VR is particularly effective for experiential learning, where learners can engage in activities that might be impossible, dangerous, or impractical in the real world. It enhances engagement and retention by providing a hands-on experience and can cater to various learning styles.
- Summary[12]
  - *Role*: A summary, often provided at the end of a learning unit, succinctly reviews the key points and concepts covered.

[5] Leenknecht, M., Wijnia, L., Köhlen, M., Fryer, L., Rikers, R., & Loyens, S. (2021). Formative assessment as practice: The role of students' motivation. *Assessment & Evaluation in Higher Education*, *46*(2), 236–255. https://doi.org/10.1080/02602938.2020.1765228

[6] Lu, C., & Cutumisu, M. (2022). Online engagement and performance on formative assessments mediate the relationship between attendance and course performance. *International Journal of Educational Technology in Higher Education*, *19*(1), 2. https://doi.org/10.1186/s41239-021-00307-5

[7] Alt, D., & Raichel, N. (2021). *Equity and Formative Assessment in Higher Education: Advancing Culturally Responsive Assessment*. Springer International Publishing. https://doi.org/10.1007/978-3-030-71644-8

[8] Margolis, A. A. (2020). Zone of Proximal Development, Scaffolding and Teaching Practice. *Cultural-Historical Psychology*, *16*(3), 15–26. https://doi.org/10.17759/chp.2020160303

[9] Delnoij, L. E. C., Dirkx, K. J. H., Janssen, J. P. W., & Martens, R. L. (2020). Predicting and resolving non-completion in higher (online) education – A literature review. *Educational Research Review*, *29*, 100313. https://doi.org/10.1016/j.edurev.2020.100313

[10] Kaltsidis, C., Kedraka, K., & Grigoriou, M. E. (2021). Training Higher Education Bioscience Students with Virtual Reality Simulator. *European Journal of Alternative Education Studies*, *6*(1), Article 1. https://doi.org/10.46827/ejae.v6i1.3748

[11] Mahendru, N., Neo, M., & Hin, H. S. (2023). Enhancing Learner Interest & Motivation in an AR supported Experiential Learning Classroom. *Proceedings of the 3rd International Conference on Creative Multimedia 2023 (ICCM 2023)*, *786*, 133.

[12] https://www.linkedin.com/pulse/why-summarizing-important-end-each-class-shanmugasundaram/

- *Rationale*: Summaries help consolidate learning by reinforcing the most important information. They aid in memory retention and provide learners with a quick reference to revisit the main ideas of the lesson.

Each of these content types contributes to a holistic learning experience. The instructional content lays the foundation, assessments gauge understanding and reinforce learning, remediation ensures comprehension, VR provides experiential learning, and summaries reinforce and consolidate knowledge. Together, they create a learning experience that supports learners in achieving mastery of the subject matter.

POLIMI team created a high range of content for each concept.

The existing content is then used by the Adaptemy AI Adaptive Learning Engine for its Large Language Model in-context learning that will facilitate content optimisation for AI-enabled adaptive learning experiences and chat-based interactions with the students (i.e., see Think-Pair-Share learning loop).

2.4.1 Assessment content

The purpose of assessment items in the context of education and learning is multifaceted [13, 14, 15], encompassing various key objectives:

- *Measuring Understanding and Mastery*: Assessment items are primarily used to evaluate how well learners have understood and mastered the subject matter.
- *Providing Feedback*: They offer essential feedback to both learners and lecturers. For learners, assessments can highlight areas of strength and areas needing improvement, guiding their future learning efforts. For lecturers, assessment results can indicate the effectiveness of their teaching methods and materials, signalling where adjustments might be necessary. For the AI Adaptive Learning Engine, evidence from assessments are used to create an accurate learner profile.
- *Guiding Instruction*: Assessment outcomes can inform instructional strategies. If a significant number of learners struggle with a particular concept, it may indicate the need for additional instruction or a different approach to the topic.
- *Reinforcing Learning*: Assessments can be further used to reinforce learning and aid in knowledge retention. The act of recalling information to answer assessment questions is a form of active learning that can strengthen memory and understanding.
- *Encouraging Self-Reflection*: Assessments encourage learners to reflect on their own understanding and learning strategies, fostering self-directed learning and personal growth.

[13] Popham, W. J. (1999). *Classroom Assessment: What Teachers Need To Know*. Second Edition. Allyn & Bacon, A Viacom Company, 160 Gould St.

[14] Jammeh, A. L. J., Karegeya, C., & Ladage, S. (2023). Application of technological pedagogical content knowledge in smart classrooms: Views and its effect on students' performance in chemistry. *Education and Information Technologies*. https://doi.org/10.1007/s10639-023-12158-w

[15] Kamalov, F., Santandreu Calonge, D., & Gurrib, I. (2023). New Era of Artificial Intelligence in Education: Towards a Sustainable Multifaceted Revolution. *Sustainability*, *15*(16), Article 16. https://doi.org/10.3390/su151612451

Overall, assessment items are crucial for a comprehensive and effective educational process, serving not only as a tool for evaluation but also as a catalyst for learning, instruction, and personal development.

POLIMI team created a high range of assessment items for each concept. Figure 7, Figure 8, Figure 9 presents some sample examples of the assessment items.

1.1 What is the core concept of recombinant technology?

- The same mRNA in different organisms leads to the expression of the same protein
- To produce a biopharmaceutical, a specific gene needs to be produced based on the microorganism selected for the process
- Only microorganisms that are able to express a protein naturally can be used for its manufacturing on a large scale
- Only bacteria are able to express proteins after they are transfected with the proper gene

1.2 What is transfection?

- The process of releasing the produced protein in the extracellular medium
- The synthesis of a protein avoiding the use of microorganisms
- The introduction of the gene encoding for the desired protein in the host cell
- The treatment of the microorganisms with antibiotics to prevent the produced protein from viral contamination

1.3 What are the pros and cons of bacteria compared to mammalian cells for the production of biopharmaceuticals?

- They grow fast but have the potential to contaminate the product
- They have fast growth kinetics but a simple metabolism prevents them from post-transcriptional modifications
- They ensure large productivities but the culture is often unstable
- They tolerate simple nutrients obtainable from wastes but are hard to be genetically manipulated

Figure 7. Sample assessment for the " Recombinant technology - processes for transfecting a cell and expand the substrate"" created by the POLIMI team

2.1 What are the characteristic phases in the microbial growth?

- Lag, logarithmic, stationary, exponential
- Lag, exponential, stationary, death
- Exponential, stationary, death
- Lag, exponential, stationary, hyperbolic

2.2 What is the definition of "primary metabolite"?

- A product that is produced concomitantly with the microbial growth
- A molecule that does not coincide with the product but is required for the cell replication
- A product that is not essential for the cell growth and is produced during the stationary phase
- A nutrient required to sustain the cell growth

2.3 What does the Monod model describe?

- The increase in the cell density during time inside a fermentation reactor
- The balance of specific cell growth rate and cell death during the stationary growth phase
- The specific consumption of a substrate required to produce a specific protein
- The substrate limitation and inhibitory effect on the maximum cell specific growth rate

2.4 Which is the main limitation in the oxygen transfer to the cells?

Figure 8. Sample assessment for the " Hybrid modelling of biological processes- Mathematical description of the evolution of a cell population, highlighting the necessity of statistical approaches"

3.1 Which is the main limitation associated to a batch bioreactor?

- The death times associated to cleaning and reactor charge limit the productivity
- A closed system often leads to culture destabilization
- The substrates are rapidly consumed, which slows down the cell growth rate
- It is not possible to properly control the quality of the product

3.2 What are pros and cons of a fed-batch bioreactor?

- The cell density is typically higher because of a better oxygen transfer but the continuous supply of nutrients alters the environment where the cells grow
- The continuous supply of nutrients allows higher cell densities, but toxic metabolites accumulate in the reactor
- The product can be controlled by properly dosing the nutrients but the accumulation of toxic metabolites reduces the maximum achievable cell density
- The cell density is higher because of a larger amount of nutrients but amount of fatty acids produced increase

3.3 Which of the following sentence referred to a chemostat is correct?

- The inlet nutrient flow rate should be kept at the maximum to promote the cell growth
- The cell density reached is typically higher than for a fed-batch
- The continuous harvest allows to remove spent media which could inhibit the cell proliferation
- It is the most employed configuration at the industrial level

3.4 What limits the productivity in a chemostat?

- The continuous removal of cells from the reactor
- The necessity of limiting the inlet flowrate to avoid wash-out conditions
- The cell instability under continuous harvesting
- The impossibility of reaching a stationary cell growth phase, for secondary metabolites

Figure 9. Sample assessment for the "Fermentation bioreactors"

2.4.3 Instructional content

The purpose of instructional content in an educational context is multifaceted and crucial for effective learning [16,17, 18, 19]. Here are the key purposes of instructional content:

- *Conveying Knowledge and Skills*: The primary role of instructional content is to introduce and teach the specific knowledge and skills that are the objectives of a course or lesson. This includes facts, theories, procedures, and methods relevant to the subject matter.
- *Structuring Learning*: Instructional content provides a structured approach to learning, guiding learners. This helps in building a foundation of basic knowledge before moving on to more complex ideas.
- *Facilitating Understanding:* It aims to make complex ideas more understandable and relatable to learners.
- *Providing a Basis for Application*: It serves as a foundation upon which learners can build as they apply concepts in practical situations, whether in problem-solving, case studies, or real-world applications.
- Assisting in Assessment Preparation: Instructional content prepares learners for assessments by covering the knowledge and skills that will be evaluated. It aligns with learning objectives and assessment criteria to ensure a cohesive learning experience.

In summary, instructional content is designed not only to inform and educate but also to engage, inspire, and equip learners with the necessary tools for understanding, applying, and extending their knowledge and skills.

POLIMI team created a comprehensive instructional for each concept. Figure 10, Figure 11, Figure 12 presents some sample examples for the instructional content.

[16] Agustian, H. Y., Finne, L. T., Jørgensen, J. T., Pedersen, M. I., Christiansen, F. V., Gammelgaard, B., & Nielsen, J. A. (2022). Learning outcomes of university chemistry teaching in laboratories: A systematic review of empirical literature. *Review of Education*, *10*(2), e3360. https://doi.org/10.1002/rev3.3360

[17] McNeill, L., & Fitch, D. (2023). Microlearning through the Lens of Gagne's Nine Events of Instruction: A Qualitative Study. *TechTrends*, *67*(3), 521–533. https://doi.org/10.1007/s11528-022-00805-x

[18] Mayer, R. E. (2014). Incorporating motivation into multimedia learning. *Learning and Instruction*, *29*, 171–173. https://doi.org/10.1016/j.learninstruc.2013.04.003

[19] Hernández-Ramos, J., Rodríguez-Becerra, J., Cáceres-Jensen, L., & Aksela, M. (2023). Constructing a Novel E-Learning Course, Educational Computational Chemistry through Instructional Design Approach in the TPASK Framework. *Education Sciences*, *13*(7), Article 7. https://doi.org/10.3390/educsci13070648

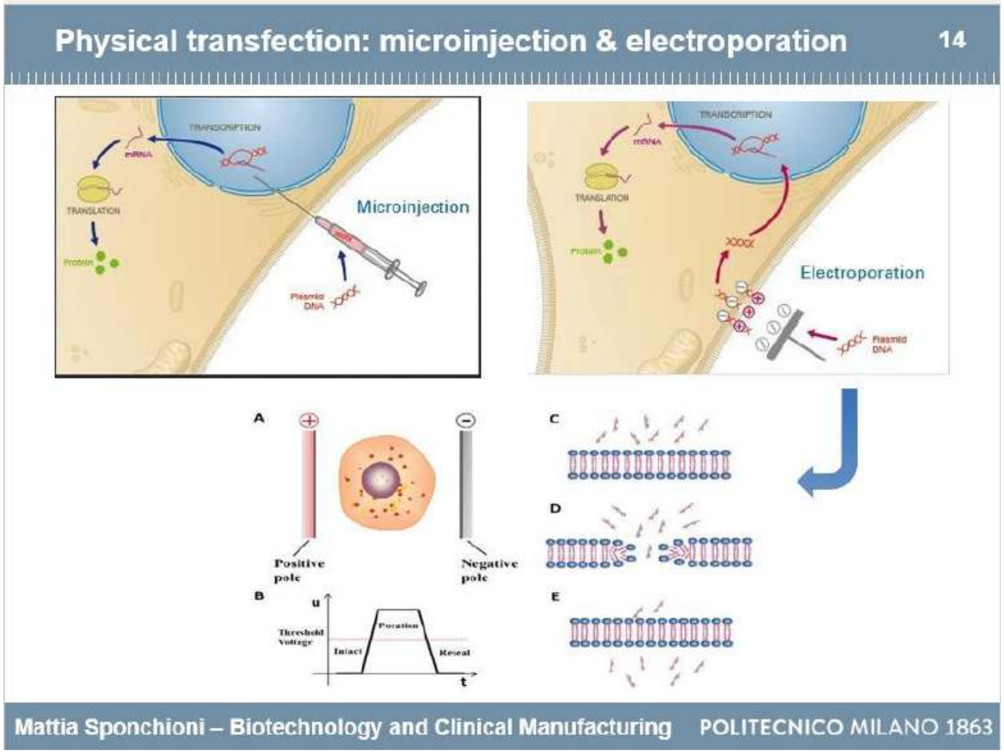

Figure 10. Sample instructional slide for the Recombinant technology - processes for transfecting a cell and expand the substrate " Concept created by the POLIMI team

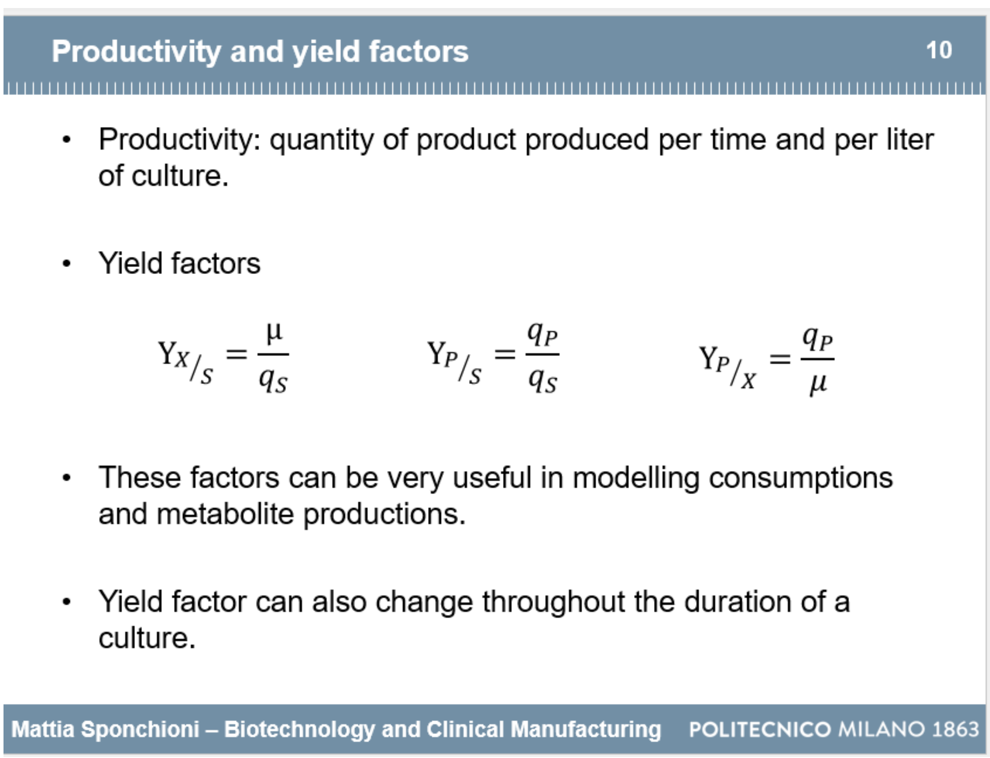

Figure 11. Sample instructional slide for the Fermentation bioreactors - Analysis of the factors affecting productivity for the different reactor configurations" Concept created by the POLIMI team

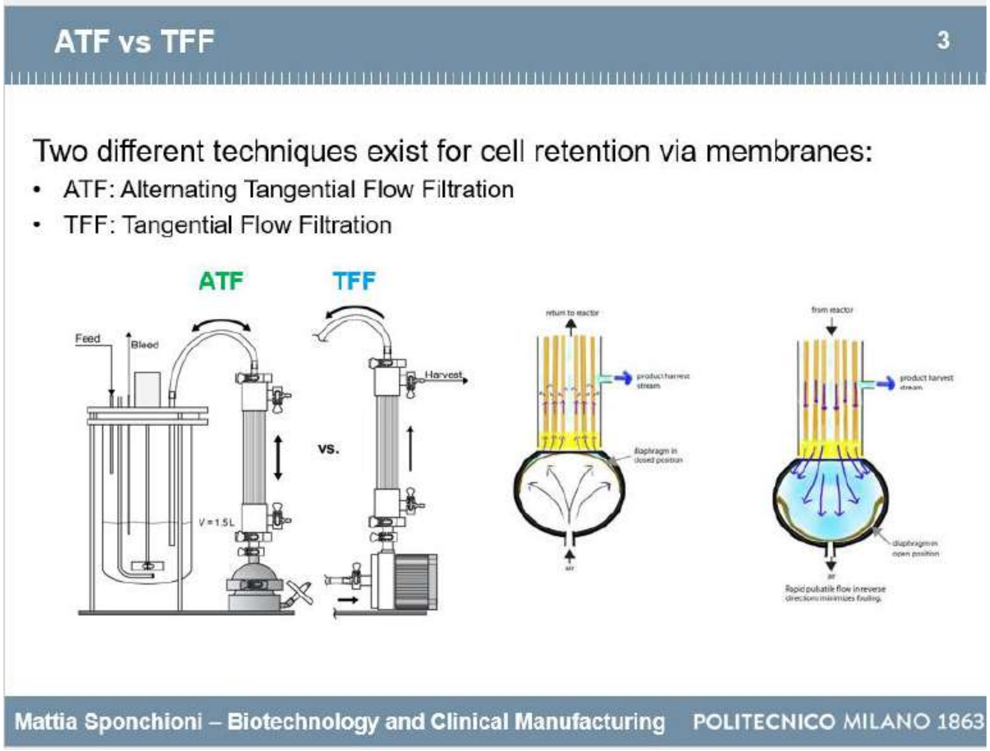

Figure 12. Sample instructional slide for 'Perfusion bioreactors - key hardware elements to realize perfusion cultures' developed by the POLIMI team

2.4.3 Remediation instructional

The purpose of remediation in instructional contexts is to provide additional support and instruction to learners who are struggling to meet the learning objectives or who have not fully grasped certain concepts or skills. Remediation is a critical component of effective teaching and learning, and its main purposes include[20,21,22]:

- *Addressing Learning Gaps*: Remediation helps in identifying and addressing specific areas where a learner is facing challenges. It aims to fill these gaps in understanding, ensuring that all students have a solid grasp of the necessary knowledge and skills.
- *Enable Personalized Learning Support*: Remediation enables personalized instruction tailored to the individual needs of each learner.
- *Reinforcing Understanding*: It reinforces learning by providing additional explanations, examples, or practice opportunities. This reinforcement helps in solidifying a learner's understanding of the material.

[20] Burleigh, C., Kroposki, M., Steele, P., Smith, S., & Murray, D. (2022). Coaching and teaching performance in higher education: A literature review. *International Journal of Mentoring and Coaching in Education*, *12*. https://doi.org/10.1108/IJMCE-12-2021-0114

[21] Griful-Freixenet, J., Struyven, K., Vantieghem, W., & Gheyssens, E. (2020). Exploring the interrelationship between Universal Design for Learning (UDL) and Differentiated Instruction (DI): A systematic review. *Educational Research Review*, *29*, 100306. https://doi.org/10.1016/j.edurev.2019.100306

[22] Margolis, A. A. (2020). Zone of Proximal Development, Scaffolding and Teaching Practice. *Cultural-Historical Psychology*, *16*(3), 15–26. https://doi.org/10.17759/chp.2020160303

- *Preventing Future Learning Issues*: By addressing learning gaps early, remediation can prevent future issues in more advanced topics that build on foundational knowledge. This proactive approach helps ensure that learners are well-prepared for subsequent stages of their education.
- *Enhancing Overall Educational Outcomes*: Effective remediation contributes to improved educational outcomes. By ensuring that all students meet the required learning objectives, it raises the overall level of achievement in a class or course.
- *Enhancing Skill Mastery*: Remediation focuses not only on knowledge acquisition but also on skill mastery, ensuring that students are able to apply what they have learned effectively.

In summary, remediation is a vital aspect of the learning process, aimed at supporting learners who need additional help. Its goal is to ensure that all students, regardless of their starting point, can achieve the learning objectives and succeed in their educational endeavours.

2.4.4 Virtual Reality

The use of Virtual Reality (VR) in teaching Chemical Engineering serves several significant purposes, enhancing the learning experience in unique and innovative ways[23,24,25,26,27]. Here are some of the key purposes:

- *Safe Simulation of Industrial Processes*: Chemical engineering often involves processes that can be hazardous in real-life settings, such as handling chemicals or operating high-pressure systems. VR allows students to simulate these processes in a completely safe environment, where they can learn and make mistakes without any risk of harm.
- *Visualization of Complex Concepts*: Many concepts in chemical engineering are abstract and complex. VR can provide a three-dimensional, immersive visualization of these concepts, making them easier to understand and more tangible for students.
- *Interactive Learning Experience*: VR creates an interactive learning environment where students can actively engage with the material. This interactivity can enhance understanding and retention of information, as opposed to passive learning methods.

[23] Hou, Y., Wang, M., He, W., Ling, Y., Zheng, J., & Hou, X. (2023). Virtual Simulation Experiments: A Teaching Option for Complex and Hazardous Chemistry Experiments. *Journal of Chemical Education*, *100*(4), 1437–1445. https://doi.org/10.1021/acs.jchemed.2c00594
[24] Chen, J., Fu, Z., Liu, H., & Wang, J. (2024). Effectiveness of Virtual Reality on Learning Engagement: A Meta-Analysis. *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT)*, *19*(1), 1–14. https://doi.org/10.4018/IJWLTT.334849
[25] Cromley, J. G., Chen, R., & Lawrence, L. (2023). Meta-Analysis of STEM Learning Using Virtual Reality: Benefits Across the Board. *Journal of Science Education and Technology*, *32*(3), 355–364. https://doi.org/10.1007/s10956-023-10032-5
[26] Yu, Z., & Xu, W. (2022). A meta-analysis and systematic review of the effect of virtual reality technology on users' learning outcomes. *Computer Applications in Engineering Education*, *30*. https://doi.org/10.1002/cae.22532
[27] Sami Ur Rehman, M., Abouelkhier, N., & Shafiq, M. T. (2023). Exploring the Effectiveness of Immersive Virtual Reality for Project Scheduling in Construction Education. *Buildings*, *13*(5), Article 5. https://doi.org/10.3390/buildings13051123

- *Hands-on Experience Without Physical Constraints*: VR technology can provide students with practical, hands-on experience without the need for physical laboratories or expensive equipment. This can be especially beneficial for institutions with limited resources.
- *Realistic Simulation of Experiments*: VR can simulate chemical reactions, allowing students to observe and interact with these reactions in real-time. This helps in understanding the dynamics of reactions and the impact of various factors like temperature, pressure, and concentration.
- *Preparation for Industry Practices*: By simulating real-world chemical engineering environments and processes, VR prepares students for what they can expect in their professional careers. This includes familiarity with industry-standard equipment and protocols.
- *Engagement and Motivation*: The novelty and immersive nature of VR can increase student engagement and motivation, making learning more interesting and enjoyable.

In summary, the use of VR in teaching Chemical Engineering provides a safe, interactive, and highly visual learning environment. It enhances the understanding of complex concepts, offers practical experiences without physical constraints, and prepares students for real-world industrial scenarios.

The POLIMI team identified experiment such *Interacting with Bioreactor Technologies* described below.

2.4.4.1 Experiment: Interacting with Bioreactor Technologies

The Bioreactor Experiment will enable students to visualize and understand the role of different components in the conduction of a bioreactor and to. understand the main input/output correlations (e.g. how the outlet flow rate impacts cell density and productivity).
The key tasks in the experiment will

- Allow the student to familiarize themselves with the lab scale reactor component, and to recognize the different components
- Allow the student to interact with the reactor configuration, by starting from the basic configuration and addition different components (i.e., vessel, inlet pump, outlet pump, filter).
- Allow the student to configure different variable and experiment what happens when certain configuration is set up
- Allow the student to adjust the process parameters related to the cell growth. The user will make use of the control panel for visualising and configuring the main parameters: temperature, PH, nutrient concentration, inlet and outlet flow rate value when applicable.
- Allow the student to interact with transversal tasks: sterilisation (e.g., cleaning components) to improve the ability in completing some tasks, and safety and protection procedures PPE.

Additional requirements were identified by the POLIMI team in the context of this experiment:

- having the feature of speeding and slowing the system is fundamental as typical fermentation processes last weeks
- VR application to be used also from home / with no 3D devices with students learning from mistakes (e.g. wrong bioreactor settings)

- tracking the media consumption (nutrients for cells) will be important as it is one of the main cost items in bioprocessing
- adding mixer animation is important to understand dissolution rates, especially for gas

3. Learning experience for the HECOF pilot

3.1 Overview of AI-enabled Adaptive Learning Experience and Learning Loops

Education historically has often implemented one-size-fits-all models that prioritize fixed outcomes rather than focusing on individual learners and their needs. However, AI-Adaptive Learning has been developed as an alternative, offering a personalized approach to meet each student's unique needs through tailored teaching methods.

AI-Enabled Adaptive Learning Systems applies artificial intelligence to customize the educational journey for each student. It analyses data on students' performance, then adjusts the learning path and content accordingly.

For AI-Adaptive Learning systems, the adaptive learning design is a thought process asking questions like 'what should the learning experience depend on?' and 'If you were the learner's personal tutor, how would you help them?' when creating the learner-centred experiences.
The learning experience design [28] is done through designing learning loops. Learning loops are then used to configure the AI-Adaptive Learning Engine to orchestrate the learning experiences for students.
Learning Loops are definable sub-component that encapsulate a learner-centred learning experience with a defined goal and a given rationale in the given context.

Using learning loops, the learner-centred design shifted the focus from instruction to learner-driven construction of an experience that is meaningful, engaging, and satisfying. It includes an understanding of the learner through the learner model and an empathetic understanding of the learner in the sociocultural and technical context through the extended learning model.
As mentioned, the focus of design is the learning experience rather than the learning tools or materials and it is focused not on learning materials only, but it builds on top of learning goals of promoting acquisition of knowledge and skills (as learning outcomes) with goals that are meaningful and relevant to the learner, aligning with the trajectory of their individual purpose and internal influences (i.e., cognitive, emotional).

[28] https://edtechbooks.org/ux/LXD_challenges

3.2 Overview of the Learning loops for the HECOF POLIMI pilot

The pedagogical principles behind the HECOF POLIMI pilot inherits the Adaptemy AI-Adaptive learning Engine's pedagogical principles:

1. Getting attention
2. Creating active engagement
3. Keeping learners "in flow"
4. Effective feedback
5. Reinforcement & Interleaved practice

Through workshops the following learning loops were defined for the POLIMI pilot.

- Intake
- Guided Mastery
- Practise
- Practise through VR
- Reinforcement
- Think-Pair-Share.

Intake are loops suitable for 'Intake' type concepts, *Guided Mastery* is suitable for concepts type: 'Knowledge Acquisition'. *Practise* loop is suitable for "Practise" type concepts. *Reinforcement learning* is suitable for 'Knowledge Acquisition' or 'Practise' concept type/
Practise through VR are suitable for 'Practise VR' concept types.
The *Think-Pair-Share* will be a topic-level learning loop.

The learning loops will be configured in the Adaptemy AI-Adaptive Learning Engine that will be used as a subcomponent of the HECOF system.

Table 2. Summary learning loops for POLIMI pilot

#1	Loop	Strategy	Goal	**Format**
1	Intake	Subset concepts "intake" adaptive assessment	To detect misconceptions (intake concepts) and to activate entry knowledge	Adaptive questions short sequence, guidance messages, adaptive-instructional, course readiness
2	Guided Mastery	Concept-level mastery learning	To build mastery of the concept To create self-awareness of progress	Schedule-aligned concept-level mastery learning, exercise questions, guidance messaging, adaptive-instructional
3	Practising	Adaptive practise on concept level through subskills	To build comprehension of practical concepts	Practising will imply a concept-level mastery strategy
4	Reinforcement	Interleaved reinforcement	To consolidate previous learning	Course-level spaced repetition of recent acquired concepts
5	Practise (VR)	VR practise	To practise experiments	Interaction through VR-based content objects
6	Think-pair-share	Virtual Subject Expert based on LLM	To offer explanations and study support	Conversational with Virtual Subject Expert based on LLM structured in a loop

3.3 Intake

3.3.1 Description

Intake learning loop will imply assessment on the intake concepts with the goal of detecting misconceptions and to activate entry knowledge.

3.3.2 Goals

Intake learning loop goals is

- To detect misconceptions (intake concepts) and to activate entry knowledge

3.3.3 Rationale

The rationale for the POLIMI Intake learning loop goals are:

- This loop is aimed to spot misconceptions (distractors) and to activate entry knowledge. After the initial lecture, students can take this loop to test for any misconceptions.
- This loop will only be given for the introductory concepts (tagged with intake)

3.3.4 Content type

Guided Mastery will include content objects such as:

- Assessment items
- Remediation instructional

3.3.5 Summary adaptation

For each concept, students will do 1 quiz (for example between 4-8 questions) and if after the first exercise we will see a low probability to pass, a remedial content (i.e., video) will be displayed followed by another quiz.

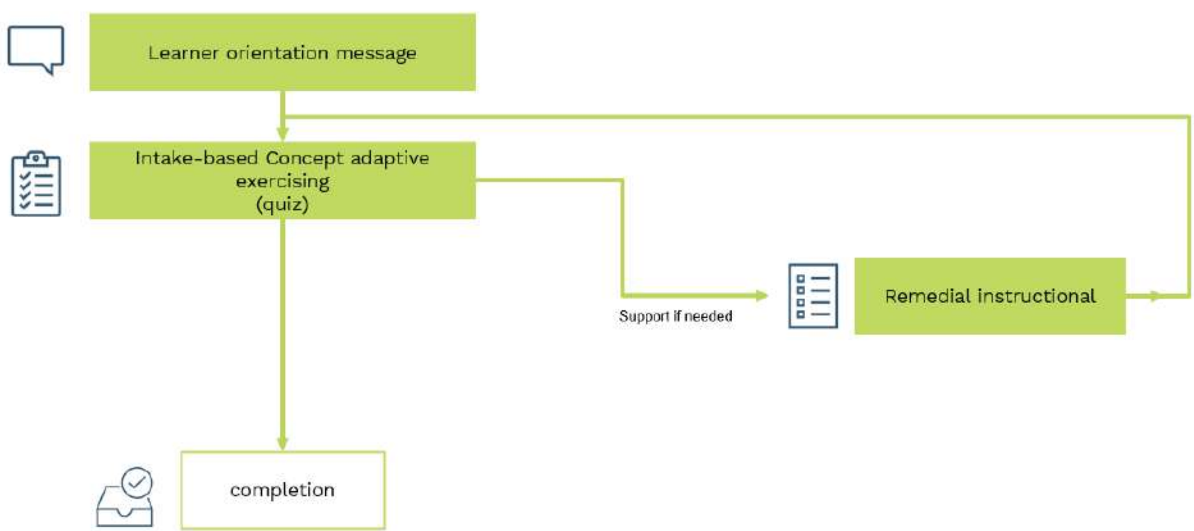

Figure 13. Intake loop (POLIMI pilot) - Schematic adaptation

3.4 Guided Mastery

3.4.1 Description

Guided Mastery will imply a concept-level mastery strategy and will progress in map-order through concepts in topic towards mastery coverage.

3.4.2 Goals

Guided Mastery learning loop goals are
- To build towards mastery of the topic
- To create self-awareness of progress

3.4.3 Rationale

The rationale for the Guided mastery learning loop (for POLIMI pilot class) goals are:
- The learning loop should implement a balanced adaptive learning approach based on all available content towards mastery of the lesson (knowledge acquisition). A lesson covers one concept.
- A strong student will most likely go through instructional and exercises (quizzes). As soon as there are signs of low success rate (lower probability to pass) alternative paths with remedial instructional content are given to the students.

3.4.4 Content type

Guided Mastery will include content objects such as:
- Instructional theory
- Assessment items
- Remediation instructional

3.4.5 Summary adaptation

The learning loop takes students through instructional content and exercises (quizzes) through easy, medium, and hard quizzes (exercises). Additional instructional where needed is provided.
Students will go progressively through easy, medium, and hard levels of knowledge acquisition.
At each level, if the students show lower probability to pass, remedial instructional content is presented followed by an additional exercise (quiz). Additional path change is available if the students struggle again.

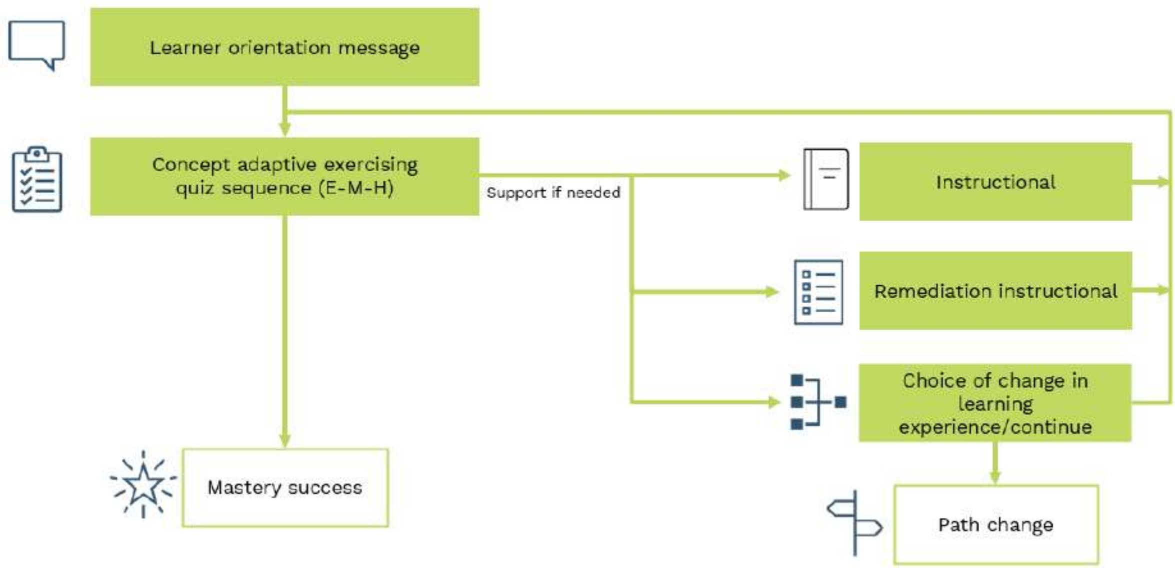

Figure 14. Guided Mastery loop (POLIMI pilot) - Schematic adaptation

3.5 Practising

3.5.1 Description

Practising will imply a concept-level mastery strategy and will progress in map-order through concepts in topic towards mastery coverage.

3.5.2 Goals

Practising learning loop goals are:

- To build towards mastery of the topic
- To create self-awareness of progress

3.5.3 Rationale

The rationale for the POLIMI learning loop goals are:

- This loop is aimed to This loop is aimed to build comprehension of practical concepts
- Content is further tagged to sub-skill (i.e., equation type). This is one loop per concept.
- This loop will only be given for the practising concepts (tagged with practising)

3.5.4 Content type

Practising learning loop will include content objects such as:

- Assessment items
- Remediation instructional

3.5.5 Summary adaptation

For each concept, students will do 1 quiz (exercise) per sub-skill (for example between 4-8 questions) and if after the first exercise we will see a low probability to pass, a remedial instructional will be displayed followed by another quiz (exercise).

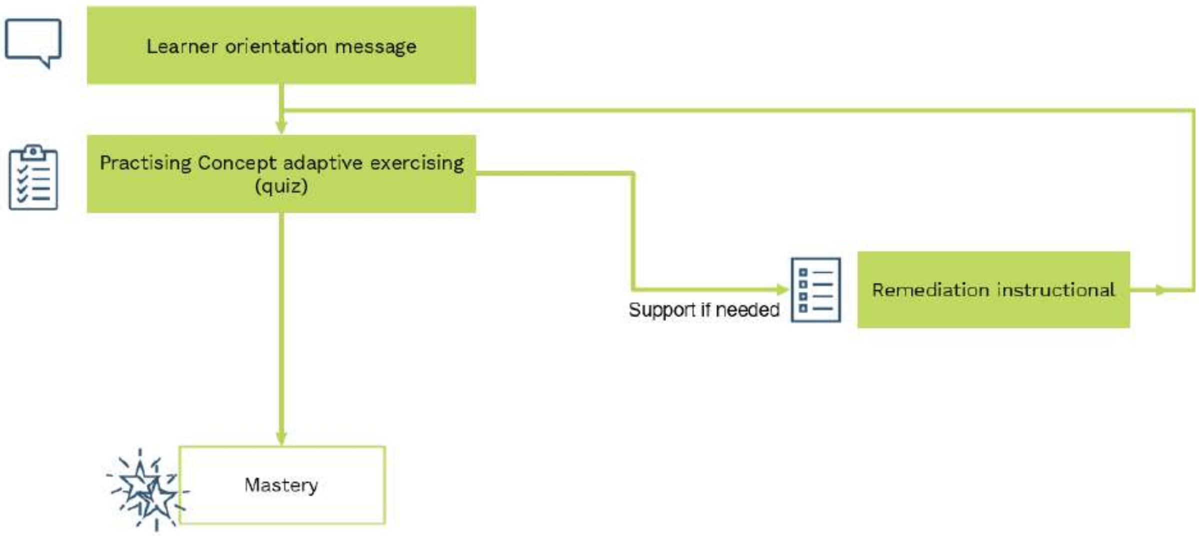

Figure 15. Practicing loop (POLIMI pilot) - Schematic adaptation

3.6 Reinforcement

3.6.1 Description

Reinforcement loop implies an interleaved reinforcement strategy and perform a course-level spaced repetition of recent acquired concepts.

3.6.2 Goals

Guided Mastery learning loop goals is

- To reinforce and consolidate previous learning

3.6.3 Rationale

The rationale for the POLIMI reinforcement learning loop goals are:

- The loop will use previous assessment items.
- This loop is aimed to give course-level spaced repetition of acquired concepts following a memory bucket approach (can be done at topic level, at strand level or at course level). Additionally, it would be recommended to have a summary of each concept. This is to be used after students have mastered the concepts.

3.6.4 Content types

Guided Mastery will include content objects such as:

- Assessment items
- Summary

3.6.5 Summary adaptation

Students will start by selecting their goal (i.e., number of questions to revise) and will answer questions from already mastered concepts. The concepts will be selected following the space repetition approach. Furthermore, a summary of the most forgotten concept will be presented to students.

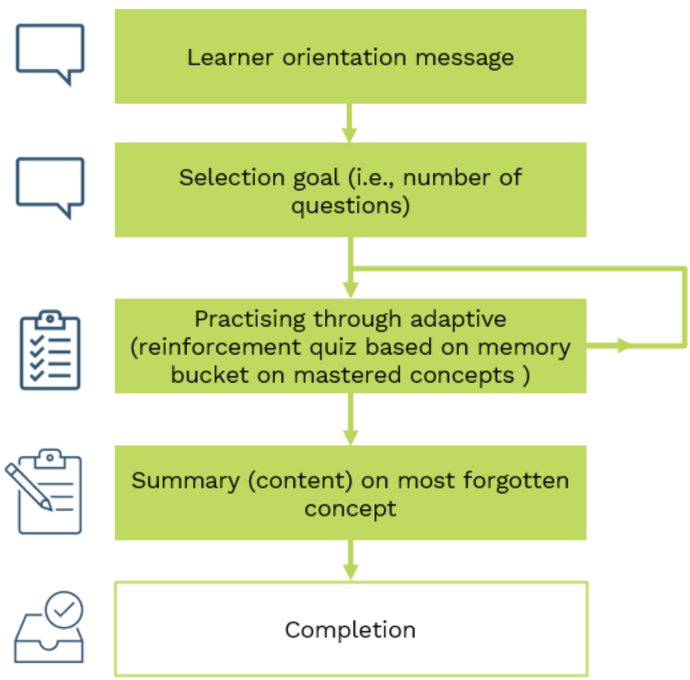

Figure 16. Reinforcement loop (POLIMI pilot) - Schematic adaptation

3.7 Practise (VR)

3.7.1 Description

Practise (VR) loop will imply a VR experience

3.7.2 Goals

Practise VR learning loop goals is:

- To enable practise on experiments

3.7.3 Rationale

The rationale for the POLIMI reinforcement learning loop goals are:

- To enable students to gain practical experience
- To enhance comprehension about practical aspects
- To make the experiments accessible to students.

3.7.4 Content types

Practise (VR) will include VR content objects.

3.7.5 Summary adaptation

The VR applications are seen as different VR content objects (VR worlds) that will be recommended to students for concepts

Inside a VR application, students will proceed through the following

1. Apparatus investigation – with the role to allow students to accommodate with VR and apparatus used in VR;
2. Guided experiment – with the role to allow students to do an experiment in a guided mode, where step by step, the experiment is explained to them;
3. Challenge experiment – with the role to allow students to do an experiment on their own.

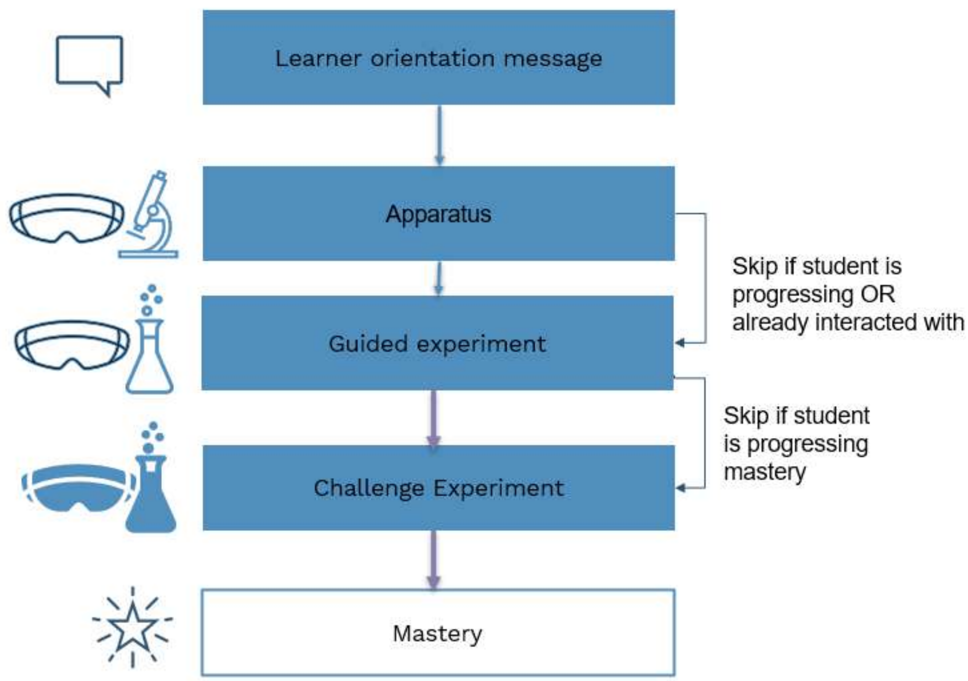

Figure 17. Practice (VR) (POLIMI pilot) - Schematic adaptation

3.8 Think-Pair-Share

3.8.1 Description

Think-Pair-Share loop will imply an interleaved reinforcement strategy and perform a course-level spaced repetition of recent acquired concepts.

3.8.2 Goals

Think-pair-share learning loop goals is:
- To offer explanations and study support [through a learning companion]

3.8.3 Rationale

The rationale for the POLIMI think-pair-share loop goals are:

- Think-Pair-Share is learning loop that offers explanations based on the course material and makes students to reflect, share notes on concept specific learning or on how the learning experience helped them understand the concept

3.8.4 Content types

Think-pair-share will make use of content from a Large Language Model trained on the course material.

3.8.5 Summary adaptation

The AI-agent will share the most recent correct and incorrect question and will provide additional explanations. The AI-agent will then open a chat as a Virtual Subject Expert and provide answers to student questions. In the end, the AI-agent will ask for any notes or reflections the student might want to share. The existing content is used by the Adaptemy AI Adaptive Learning Engine for its Large Language Model in-context learning for the AI-Agent as Virtual Subject Expert chat-based interactions with the students.

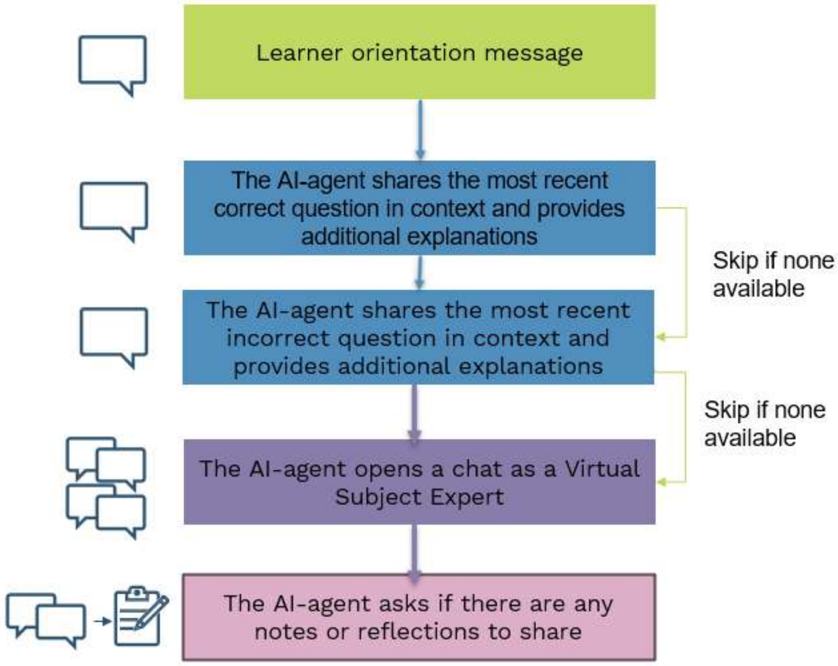

Figure 18. Think-pair-share loop (POLIMI pilot) - Schematic adaptation

4. Conclusions

This document presented the Learning Design Document for POLIMI pilot class. It detailed the learning objectives of the course for the POLIMI pilot class, provided an overview of the curriculum mode underlying the POLIMI pilot class, presented the learning loops design of the POLIMI pilot class.

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