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[101086701] Discovery Space:
An AI-Enhanced Classroom for Deeper Learning in STEM

D.2.2 Deeper Learning Competence Framework

WP2 Discovery Space Innovation Model: Vision and Reflection

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Executive Summary

This document (Deliverable D2.2) presents the Deeper Learning Competence Framework and describes the approaches and the environments that could facilitate the development of proficiency in Deeper Learning. It highlights the key role of the exploratory learning environments and more specifically the online (both virtual and remote) labs that could be combined with the provision of scaffolds (through the use of AI learning companions) while students are performing inquiry-based tasks.

In the Introduction of the document, we give the definition of Deeper Learning as it can be found in the literature and a brief description of the Deeper Learning Classroom that is developed within the framework of the Discovery Space project and then we discuss the ways that AI can be exploited for educational purposes. We focus on the AI-driven lifelong learning companions and the AI-enabled continuous assessment as means to enhance the students' motivation and enhance their learning outcomes, respectively.

In Section 2 we present a detailed discussion on the value of a competence framework. The competencies from which Deeper Learning consists, namely *problem-solving competency, self-regulated learning, collaboration, creativity and innovation, digital literacy, metacognitive skills, emotional intelligence, global and cultural awareness, and ethical and social responsibility*, are explicitly discussed. Accordingly, the Discovery Space Deeper Learning paradigm is introduced which aims to cultivate profound comprehension, critical thinking, and problem-solving abilities for students. Finally, a brief overview of the three-domain competence model for Deeper Learning is given, followed by a description of learning environments that promote deeper learning competencies.

In Section 3, we emphasize the importance of the assessment of problem-solving competence, and reasoning skills, which are of fundamental importance for science learning. Within the framework of the Discovery Space project, several educational scenarios will be developed that will emphasize the development of such skills. Accordingly, we mention the five phases from which a Discovery Space scenario consists of and then we introduce the problem-solving competence assessment model that Discovery Space is proposing. The different phases of the scenario are assigned a weighting factor which is multiplied by a function that is characteristic of the student's performance at the specific phase.

In Section 4 an example of an indicative scenario from the field of Physics is presented, concerning the study of simple pendulum. The scenario is structured following the inquiry process. A student needs to react to a series of challenges during each phase, before moving on to the next one. According to the student's reactions, the AI conversational agent is drawing a learning path tailored to his/her specific needs. Students who demonstrate lower levels of understanding need to perform certain tasks provided by the AI agent, while students with moderate performance receive guidance by the agent before moving forward. Our main goal is for students to create their own knowledge and acquire an in-depth understanding of the phenomenon and the scientific process overall. For students who demonstrate higher level of understanding, they are further challenged against actual experimental data and in this way, we aim to test how confident these students are in their understanding of the concept under study.

In Section 5 the AI expected contribution becomes the focal point. First, we give a detailed presentation of the goals that should be fulfilled through the design of the Exploratory Learning Environment (ELE). More specifically, such an environment should allow students to perform their own personalized experiments and contribute to the development of key skills, thus it is crucial for the transition from the typical classroom to the Deeper Learning

Classroom. Accordingly, the inferencing capabilities of the AI lifelong learning companion are discussed. Finally, this section describes the steps towards the re-optimization of the assessment model introduced in Section 3, so that it can consider more educational data and be better applicable to classroom situations.

Finally, in Section 6 the conclusions from the work performed so far are mentioned, and the role of this document as a reference point for Work Packages 3 (technical requirements) and 4 (scenarios design) is highlighted.

List of Terms and Abbreviations

Term/Abv.	**Definition**
AI	Artificial Intelligence
AR	Augmented Reality
CPS	Collaborative problem solving
DLCF	Deeper Learning Competence Framework
IBL	Inquiry based learning
NRC	National research council
PBL	Problem-based learning
PISA	Programme for International Student Assessment
PSC	Problem solving competency
STEM	Science Technology Engineering Mathematics
VR	Virtual Reality

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1. Introduction

Over the course of the last decades several scientific and technological advances took place, which had a significant impact on the structure of modern society. Today's people need to be able to adapt fast to such changes, while being able to learn new things and apply their knowledge to cope with arising challenges of the 21st century, be competitive in the job market and in general be engaged citizens. It is well known that education plays a crucial role towards the achievement of the previously mentioned goals, with deeper learning being in the spotlight as the means which will guarantee that future school and university graduates will be equipped with the skills required to live in a constantly changing world.

According to the William and Flora Hewlett Foundation [1], deeper learning refers to a way of learning, as well as a set of competencies that the students need to develop. The definition of deeper learning according to Ref. [1] is the following: "*A set of competencies students must master in order to develop a keen understanding of academic content and apply their knowledge to problems in the classroom and on the job*". According to Ref. [1], these competencies are *mastery of academic content*, *critical thinking and complex problem solving*, *effective communication skills*, *collaboration skills*, *an understanding of how to learn* and *the growth of academic mindsets*. Such competencies can be classified into three domains, which are the cognitive, the intrapersonal and the interpersonal. According to Hilton [2], the different competencies within the different domains are:

- **Cognitive**: Cognitive processes and strategies, knowledge, creativity, critical thinking, information literacy, reasoning, innovation
- **Intrapersonal**: intellectual openness, work ethic and consciousness, flexibility, appreciation of diversity, initiative
- **Interpersonal**: teamwork and collaboration, leadership, communication, responsibility, conflict resolution

A detailed description of the Deeper Learning Competence Framework will be given in Section 2 of this document and can also be found in the deliverable D1.2 written for the purposes of the STORIES of Tomorrow project [3].

After mentioning the definition of deeper learning and the three domains that the different competencies can be classified, the question rises on how deeper learning can become possible and which means should be used for that. In a work published a few years ago, Dede [4] tried to answer these questions by arguing that new teaching strategies should be applied, e.g., collaborative investigations, extended inquiries and interdisciplinary projects, while he also claims that if such teaching methods are to be applied, schools should be equipped with up-to-date technological infrastructure. Two main reasons are given to support the use of technology to teach for deeper learning, the first being affordability and scale and the second the students' learning strengths and preferences. In the first case, the author states that traditional approaches will eventually become cost-prohibitive, while in the second case, one must consider how the use of technology outside school is changing the characteristics of students and shapes their learning strengths and preferences.

The use of technology should take place in a way which supports the achievement of the specific educational goals set, while it is also important to integrate technology in the educational process to offer to the students new learning opportunities and resources [4]. In his work, Dede mentions five technologies which could be used in the pursuit of deeper learning, namely *collaboration tools* including Web 2.0 technologies, *online and hybrid educational environments*, *tools that support learners as makers and creators*, *immersive media* and *games and* *simulations*. Moreover, Dede [4] is describing two approaches for the implementation of technology as means to achieve deeper learning. Both approaches are the result of a combination of the above-mentioned technologies and are based on the use of Technology Enhanced Learning Environments (TELs) and immersive authentic simulations (IAS).

In the latter approach the aim is for the students to have a comprehensive and realistic experience, in a virtual environment, which eventually will help them to master the deeper learning skills mentioned above. Two types of immersive environments are described in Ref. [4], multiuser virtual environments and augmented reality. The latter plays a crucial role within the Discovery Space project, as it enhances the learning experience by superimposing virtual information on real world environments. In what concerns TELs, they are carriers of curriculum content in a teacher-led instructional environment [4]. According to Ref. [4] TELs are contributing to deeper learning in the following ways, for the promotion of knowledge integration, for the promotion of collaborative learning and for providing personalized instruction. Such ways of fostering deeper learning are incorporated in the Discovery Space project, while the integration of AI is expected to have a disruptive impact on the learning process. In the following subsection we elaborate on the potential benefits that AI is expected to have in education and subsequently in the cultivation of students' deeper learning competencies, which is the main topic that this document aims to address.

1.1. Purpose and scope

According to a recent report by UNESCO on AI and education [5], three innovative ways in which AI can be exploited for common good in education are suggested and described. These are *AI-driven lifelong learning companions*, *AI-enabled continuous assessment* and *AI-enabled record of lifelong learning achievements*. The latter is beyond the scope of this document and will not be covered here. The other two ways are directly linked to an efficient and innovative way that the competencies being in the core of the Deeper Learning Competence Framework can be developed, while they are also in the heart of the Discovery Space project. In more detail, as has already been described in the deliverable D2.1 "STEM Education Future Challenges Report", the *AI-driven lifelong learning companion* is part of the Deeper Learning Classroom, which will be an environment fostering skills such as collaborative work and learning, critical thinking and mastery of academic content. The companion will always provide support, guiding the student along an individualized learning pathway, as shown in Figure 1 .

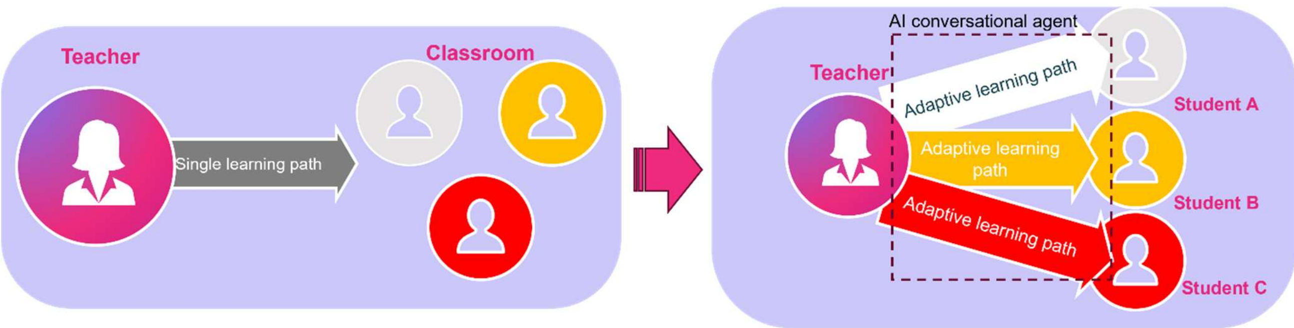


Figure 1: The transformation of the traditional classroom towards the deeper learning classroom. Each student follows a personalized learning pathway adapted to his/her needs, scaffolded by an AI-enabled learning companion. A more personalized instruction is achieved in this way, favoring deeper learning.

In this way, specific misconceptions can be addressed and targeted feedback can be provided, for each student. Moreover, in the setup shown in Figure 1, the teacher can follow in real time each student's progress. Furthermore, the AI learning companion will be able to know the student's specific interests and provide relative material to encourage them during the learning process and enhance their motivation. Though such an intrinsic motivation is present in students, it is often suspended by the educational system, as it forces students to follow a unique learning path, not taking their specific needs and interests into account [6]. Motivating students to acquire new knowledge could in turn make the fostering of deeper learning, through the development of the skills that it consists of the next logical step in the educational process.

In what concerns the *AI-enabled continuous assessment*, our main goal here is to employ AI to ensure an in-depth understanding of the subject under consideration instead of a superficial explanation through the memorization of definitions and specific problem-solving techniques, which aim in a high score at an exam. As mentioned above, the AI learning companion can assess and keep track of each student's progress and constantly pass this information to the teacher, thus beyond an opportunity to assess in depth-understanding, which is rather difficult to be done through conventional high-stakes stop-and-test examinations [6], certain Deeper Learning skills, such as problem-solving competence (PSC), can also be measured. In what concerns Problem-Solving Competence, according to PISA 2012 [7], the main benefit of a computer-based assessment of the specific skill is that data concerning specific problem-solving processes and strategies can be collected and analyzed. A detailed discussion about Problem-Solving Competence assessment process is given in Section 3.

1.2. Structure of the document

The document has been structured in the following way:

- Section 2 gives a general description of the Deeper Learning Competence Framework (DLCF). The skills at the core of the DLCF are mentioned and each of them is explained in detail. It further analyses the key role of the Exploratory Learning Environment and that of the AI-Learning companion that will provide scaffolds to students' inquiry.
- Section 3 focuses on the development of students' problem-solving competency. Moreover, in this section we discuss the phases of a Discovery Space scenario and introduce the Discovery Space model to monitor and assess the partial abilities of the Problem-Solving Competence.
- Section 4 describes an indicative Discovery Space scenario from the field of Physics. The different phases of the scenario are mentioned, and it is shown how the structure of such a scenario is helping the students to develop their problem-solving skills, while other skills in the core of the Deeper Learning Competence Framework are also developing.
- Finally, Section 5 focusses on the AI expected contribution and describes the goals that should be accomplished through the design of the project's Exploratory Learning Environment (ELE). Moreover, we discuss how the assessment model introduced in Section 3 could be further optimized.

2. Deeper Learning Competence Framework

This report commences with a comprehensive overview of Deeper Learning. Initially, we elucidate the concept of a competence framework, examining its definitions and applications within educational contexts. This is followed by an extensive review of the relevant literature, aimed at extracting a refined and encompassing definition of Deeper Learning. Building on this foundation, we identify a Discovery Space Paradigm for Deeper Learning. Subsequently a competence framework is developed, which is predicated on this paradigm. This framework is meticulously structured around the tripartite model of competence domains, ensuring a thorough and systematic approach to understanding Deeper Learning. As a nexus to the second part of the report, focusing on problem-solving competency and the Discovery Space Scenarios, we engage in a detailed discussion of various Learning Environments. This discussion is pivotal in understanding how these environments can be helpful in promoting and enhancing the efficacy of Deeper Learning strategies.

2.1. The value of a Competence Framework

A competence framework, also known as a competency framework or skill framework, is a structured and systematic way to define and organise the skills, knowledge, behaviours, and attributes that are required for individuals to perform effectively in a specific job or role within an organisation. Competence frameworks are essential in sectors like human resources for criterion-based selection. In education, they offer an opportunity to refine curricula and develop training programs that foster key competencies [8].

Competencies are instrumental in realising organisational objectives, which, for our purposes, align with fostering a sustainable society's mission and vision. These competencies may be technical, denoting specific skills, or behavioural, reflecting interpersonal attributes and attitudes. Utilising descriptors and indicators facilitate the assessment and quantification of an individual's competencies, not for categorisation but for gauging proficiency levels. This approach encourages self-assessment and continuous personal growth. Within the scope of our project, such indicators are also valuable for evaluating the efficacy of additional training interventions.

2.2. What is Deeper Learning?

Deeper learning is not just about acquiring knowledge;
it's about unlocking the potential within each learner to think critically, solve complex problems, and become an active participant in shaping their own future.
Discovery Space

Teaching for "Deeper Learning" is a comprehensive educational approach that goes beyond traditional learning methods. It emphasises not just the acquisition of knowledge but also the development of critical skills and competencies that are essential for success in the 21st century. Deeper learning prepares students for college, the world of work, and life in general, equipping them with the necessary skills and knowledge [9]. Therefore, successful internalisation of conceptual content knowledge and the automatization of subject-specific procedures, skills, and strategies are needed [10]. To gain deeper knowledge, students need to develop *core competences*, which are *problem-solving, critical thinking, self-regulated learning,* and *effective collaboration* [11,12]. These skills are crucial for developing innovative solutions to global challenges [11].

In a learning environment that promotes Deeper Learning, students are engaged deeply in the learning process, often through innovative methods like flipped classrooms, where an active, critical way of learning is provided

[13]. A Deeper Learning Environment is designed with the three core factors of **Mastery, Identity** and **Creativity** [14]. **Mastery** means not only that students master the basics of learning, or the development of disciplinary literacies and transferable knowledge through various means like student engagement, knowledge construction, and active demonstration of understanding [15]. Student mastery is achieved when the learning environment facilitates students becoming experts at their own learning process. **Identity** refers to the recognition by students of the significance and relevance of the subject matter and corresponding techniques, enabling them to internalize the topics as personally relevant and meaningful. This makes learning for grades to meaningful learning for live [16]. **Creativity** is a large construct with many different aspects, which emphasises its underestimation to date. On one hand, creativity represents mental agility, which can promote critical thinking [17]. On the other hand, it involves an open-minded approach that encourages innovative ideas and openness, a crucial trait in a rapidly evolving, intercultural world grappling with global issues [18]. This and the ability to enter a state of flow, which can develop with creativity, also promote resilience, mental well-being, and professional performance [19]. These perspectives highlight the multifaceted nature of deeper learning, encompassing a range of competencies, approaches, and outcomes relevant to educational settings and beyond.

2.3. Competencies for Deeper Learning

To achieve deep learning, a range of competencies need to be practised and developed. These competencies extend beyond mere knowledge acquisition, focusing on the application, analysis, synthesis, and evaluation of information. These competencies, as outlined in the literature, are interrelated, and often developed simultaneously through various learning experiences and environments. They equip students not just for academic success but also for effective and responsible participation in the modern world. The Deeper Learning competencies are summarized in Table 1.

Table 1: Deeper Learning Competencies

Critical Thinking and Problem Solving	The ability to analyse complex problems and devise innovative solutions is central to deeper learning.	[17,20]
Self-Regulated Learning	Self-directed learning trains students to set personal learning goals, organise time and evaluate own progress. The student instead of the teacher takes responsibility for learning.	[21,22]
Collaboration and Communication	Working effectively in groups and communicating ideas needs training, self-reflection - and empathy (→ EQ)	[22,23]
Creativity and Innovation	Creativity is not (just) about arts or innovative output but also involves understanding complex concepts, developing skills, and fostering dispositions that are crucial for comprehensive learning.	[24,25]
Digital Literacy	Actively utilising the advantages and disadvantages of digital resources in lessons must be part of contemporary education of “digital natives”.	[26,27,28]
Metacognitive Skills	Self-Reflection and Mastery of one’s own learning process. It contributes to self-efficacy, self-determination, and fruitful error management culture.	[29,30]
Emotional Intelligence (EQ)	Recognizing and managing one’s own emotions, as well as empathizing with others is basis for communication, collaboration, peaceful conflict management and error management culture.	[31]
Global and Cultural Awareness	For collaboration both understanding and appreciating cultural differences and awareness of global issues is crucial.	[32,33]

Ethical and Social Responsibility	Moral development is an important goal of education. Ethics are highly contingent on cultural circumstances. In a globalised world, contemporary liberal ethics standards and responsibility awareness are essential.	[34]
References are exemplary without rating		

2.4. The Discovery Space Deeper Learning Paradigm

The Deeper Learning Paradigm represents an advanced educational framework aimed at cultivating profound comprehension, critical thinking, and problem-solving. This paradigm marks a progression from conventional pedagogical methods, striving to prepare students for the multifaceted challenges, which are characteristic of the 21st century. Central to the Deeper Learning Paradigm is the integration of traditional academic knowledge with a suite of interdisciplinary skills crucial for contemporary success. These encompass critical thinking, collaboration, effective communication, creativity, and autonomous learning. The paradigm propels students to actively engage in their educational journey, thereby equipping them with the competencies needed to navigate a constantly evolving societal and professional landscape. In the following we discuss the competencies we consider as the key attributes of the Deeper Learning Paradigm.

In-Depth Mastery of Core Academic Subjects involves students attaining a comprehensive understanding of fundamental academic disciplines, such as mathematics, science, language, arts, and social studies, with an emphasis on practical application in real-world scenarios. Students develop **enhanced Critical Thinking and Problem-Solving**. Adequate analytical skills and problem-solving capabilities, enable them to critically assess information, evaluate evidence, and conceive innovative solutions to complex issues. The Deeper Learning Paradigm emphasizes the significance of teamwork and proficient communication. Through group endeavours, discussions, and presentations, students refine their interpersonal skills, collaborative abilities, and clarity in articulating their thoughts, developing **Collaboration and Communication skills**. Educational experiences enabling Deeper Learning are crafted to be relevant to real-life contexts, linking classroom learning to tangible applications. **Authentic and Practical Learning Experiences** involve students in projects and activities that simulate challenges they might face in future professional or community settings. Furthermore, Deeper Learning Environments motivates students to take charge of their learning process, developing skills in goal setting, time management, resource utilization, and self-evaluation. **Self-Directed Learning** approach nurtures a sense of responsibility and lays the foundation for lifelong learning. A global society with highly developed technology must also design education accordingly. **Integration of Technology in Learning** augments learning experiences. Technology is woven into the curriculum to support research, collaborative efforts, creative expression, and the cultivation of digital literacy.

However, the transformation extends beyond merely modifying the learning environment, resources, and pedagogical techniques; it also encompasses a significant shift in the mindset and approach of educators compared to a century ago. In contrast to the educational paradigm of the previous decades, where public schools primarily prepared individuals for roles within a hierarchical societal structure, contemporary education aims to cultivate individuals as responsible citizens in a democratic and sustainable society. In the contemporary context, education places greater emphasis on the development of skills like responsibility and cooperation, as opposed to the traditional paradigm, that prioritizes compliance and strict adherence to guidelines.

The implementation of the Deeper Learning Paradigm necessitates a transformation in instructional methodologies, with educators serving as **facilitators, mentors,** and **guides**. They foster an environment conducive to exploration, inquiry, and critical reflection. Assessments within this paradigm focus on gauging students' comprehension, application of knowledge, and skill development, often through performance-based evaluations and authentic tasks. The overarching aim of the Deeper Learning Paradigm is to prepare students with the requisite knowledge, skills, and mindset to excel in a rapidly evolving global context, where adaptability, creativity, and problem-solving skills are highly prized.

2.5. A Three Domain Competence Model for Deeper Learning

A category system that focuses on the desired learning objectives can be helpful in developing lessons. The Competence Model for Deeper Learning presented below can provide support with this. Deeper Learning Competence Framework based on the "Three domains of competences" (cognitive, intrapersonal, and interpersonal) and integrated with the "Four Competences" (ways of thinking, ways of working, tools for working, and living in the world) emphasize a holistic approach to skill development. A holistic approach that balances and integrates all domains and competences is essential for a comprehensive deeper learning experience [35,36].

Table 2: Deeper Learning Framework based on the three domains of competencies and the four core competencies.

	Cognitive Domain *intellectual abilities, understanding*	**Intrapersonal Domain** *self-management: emotional intelligence, self-regulation*	**Interpersonal Domain** *interacting effectively with others: communication, collaboration, empathy*
Ways of Thinking *critical thinking, creativity, learning to learn, metacognition*	deep understanding effective problem-solving	self-directed learning, innovative thinking	
Ways of Working *communication and collaboration*			*effective* teamwork and interaction
Tools for Working *information literacy, ICT literacy*	*effectively* utilize tools for learning and working		
Living in the World *Citizenship, career, personal and social responsibility*		self-awareness adaptability	understanding and participating *effectively* in societal and global contexts

2.6. Pedagogical Approaches promoting Deeper Learning Competencies

To effectively promote deeper learning competencies, educators can employ a variety of teaching interventions, forms, and methods, each supported by educational research and literature.

Project-Based Learning, Inquiry-Based Learning (IBL), Problem-Based Learning, Challenge-Based Learning (CBL), and Case-Based Teaching (CBT) are five educational approaches that share commonalities in promoting **active**, **engaged, student-centred** learning, promote competences like **critical thinking, collaboration,** and **problem-solving** and connect learning to real-world applications. But they differ in focus, structure, and pedagogical strategies.

Project-Based Learning involves students working on a project over an extended period, culminating in a final product or presentation. It emphasizes real-world relevance and interdisciplinary learning, fostering 21st-century skills like technology use, communication, and advanced problem-solving [37,38]. **Inquiry-Based Learning (IBL)** focuses on the process of exploring and investigating. Students formulate questions, conduct research, and draw conclusions, enhancing achievement and fostering positive attitudes towards learning [39,40]. Centred on solving specific problems, **Problem-Based Learning** develops critical thinking and analytical skills through the experience of solving open-ended problems [41,42]. **Challenge-Based Learning (CBL)** is a collaborative, hands-on approach where students address real-world challenges. It integrates technology and emphasizes creativity and practical problem-solving. It helps developing a helpful error-management-culture [25]. **Case-Based Teaching (CBT)** involves the use of real-world cases to stimulate discussion, analysis, and problem-solving. It helps students develop analytical skills and apply theoretical knowledge to practical situations, often used in disciplines like business, law, and medicine [43,44]. A **Service Learning**, combining community service with learning objectives is a special form of case- or challenge-based learning in which (social) responsibility and effectiveness can be experienced [45].

The list helps to clarify the key differences between the comparable approaches:

- Project-based Learning focuses on extended projects with tangible end products.
- IBL is inquiry and investigation centred.
- Problem-Based Learning is oriented towards solving specific problems.
- CBL involves addressing real-world challenges with practical solutions.
- CBT uses real-world cases as the basis for learning, focusing on analysis and application.

We require novel approaches to obtain and give **feedback**. Providing feedback is an important responsibility. Grades and efforts to offer commendation often result in decreased motivation. They condition students to depend on extrinsic motivation, which can lead to punishment avoidance tactics when grades are involved. To reframe feedback as constructive criticism, innovative assessment techniques and instructor training in feedback culture are necessary **Feedback and Reflection** is both a skill and a learning promoter [46]. **Challenge-Based Learning** enables students to generate their own feedback, fostering their ability to reflect on their plans, actions, and reasons for success and failure. CBL is classified as a **Metacognitive Strategy**, tasked with instructing students to reflect on their thinking [29]. While **Formative Assessment** necessitates a new culture of dialogue, it is a promising technique for promoting independence [47].

The fact that topics are more complex on closer inspection than linear ways of thinking would make them appear must be experienced and experienced as harmless to be able to endure resilience in the face of the ambiguity of the complex reality of a global society with constant access to the constantly developing sciences. **Interdisciplinary teaching** makes it possible to recognise and cope with the complexity of topics [48]. With the interdisciplinary approach, **Collaboration** can also be practised among teachers. It is not only students who need a group-based environment for cooperative work to experience problem-solving and learning together [22]. Another form of Collaborative Learning is the **Flipped Classroom**, in which students explore content at home and then apply knowledge in the classroom. This fosters self-determination, self-efficacy and communication, promoting motivation and responsibility [49]. As in all lessons in which students share their interim results, they practise presentation, communication and dialectics. A special form is the **Socratic Method**, in which communication skill and critical thinking are used in cooperative argumentative dialogue [50].

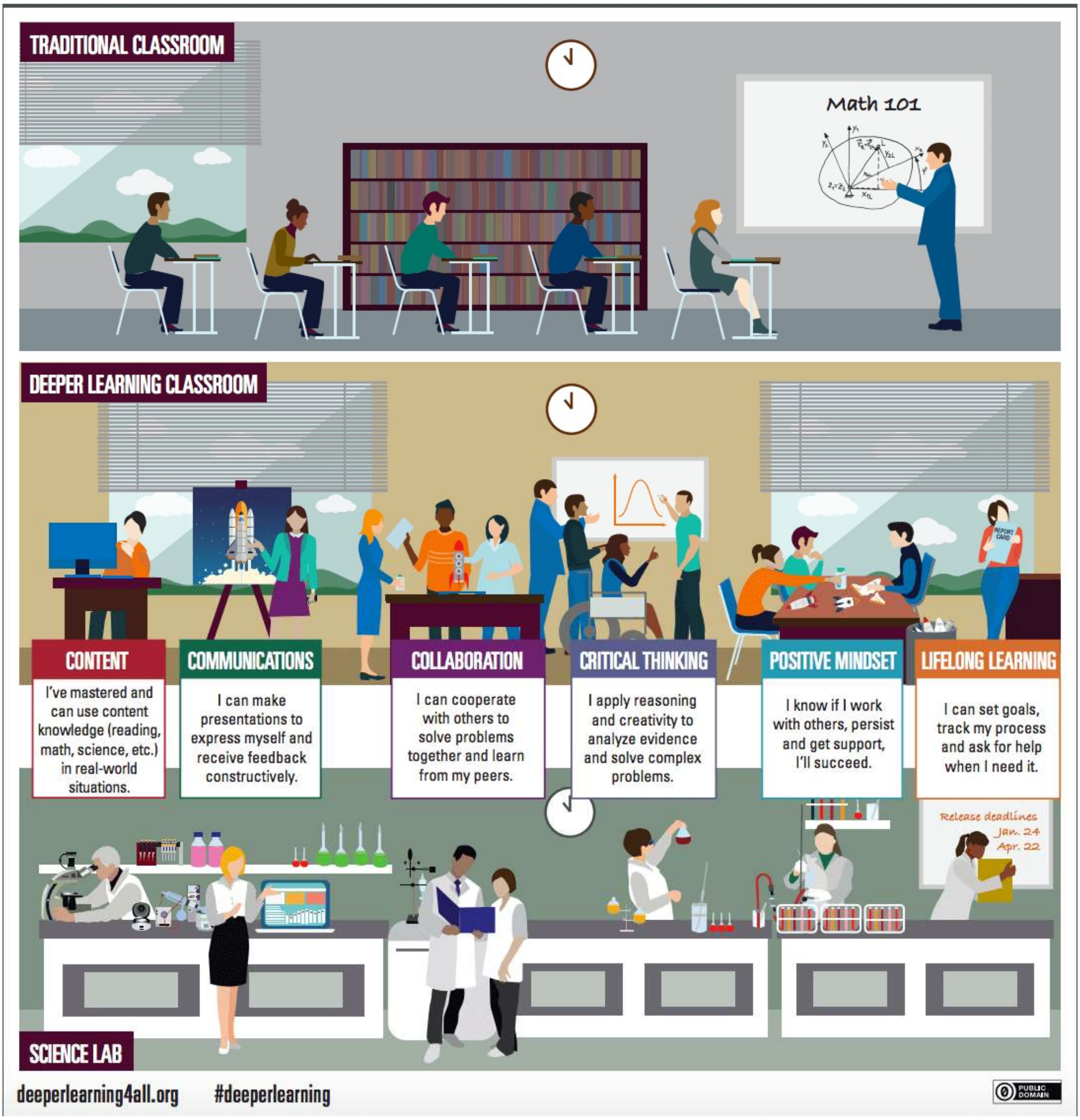


Figure 2: The Deeper Learning Classroom [1].

The last thing to mention is where learning began and should always begin with play. Studies point to the nature of play as a learning environment. Students can develop respectful language and literacy practices through play-based pedagogies, demonstrating competence in understanding language, bodies, movement, and space in early-childhood education contexts [51]. Therefore, the application of game elements in learning in the **Gamification and Simulation** of learning environments is a promising tool for providing both motivation, self-directed learning and increase in knowledge. Online learning environments and more specifically virtual and remote labs are promising tools for combining gamification and learning in the classroom.

These methods, grounded in educational research, are not only effective individually but can also be combined in various ways to suit different educational contexts and student needs. The overarching goal is to engage students actively in their learning process, encouraging exploration, questioning, and application of knowledge.

2.7. Inquiry learning and TEL environments

Discovery Space focuses on engaging students in inquiry learning based on remote and virtual labs and databases (online) labs to develop their competence in solving complex problems and enculture them in science communities. In the current section we first describe what is currently known about inquiry learning with simulations and remote and virtual labs, as well as their current implementation paradigms, and then we discuss how the Discovery Space project will bring the current state of knowledge a step further.

Nowadays there is at large consensus that inquiry-based approaches to learning science incorporating students' active investigation and experimentation are necessary to motivate students for science and that, therefore, inquiry should be part of the curriculum also because inquiry skills have a value on their own. Inquiry is the process in which students are engaged in scientifically oriented questions, perform active experimentation, formulate explanations from evidence, evaluate their explanations considering alternative explanations, and communicate and justify their proposed explanations.

Contemporary, Technology Enhanced Learning (TEL), approaches to science learning provide students with ample opportunities for inquiry. TEL environments that offer simulations, games, data sets, and/or remote and virtual laboratories are significant in this respect. In these environments technological affordances are directly used for pedagogical purposes in that inquiry calls for non-linear, manipulable, and runnable content which technology can offer. Evidence is accumulating that TEL inquiry environments provide students with genuinely effective learning opportunities and large-scale studies show that, on different outcome measures, TEL-based inquiry outperforms more direct approaches to instruction [52]. These promising results, however, only hold when the inquiry process is structured and scaffolded. Scaffolds thus play a pivotal role in inquiry learning. Scaffolds come in many kinds. Examples are tools to create hypothesis, data analysis tools, and tools to save and monitor experiments.

Currently a growing number of TEL inquiry environments have emerged that provide students with inquiry facilities together with integrated supportive structure and scaffolds. Two characteristics such environments are the Go-Lab (https://www.golabz.eu/) and Inspiring Science Education (https://inspiring-science-education.net/).

Discovery Space follows the approach of inquiry learning as exemplified in the projects mentioned above and in doing this we focus on (combining) remote and virtual labs and integrate them with supportive structure and scaffolds. More specifically Discovery Space will design an Exploratory Learning Environment (see D3.1) to facilitate students' inquiry and problem-solving while they are working with virtual and remote labs. This environment will be enabled with an AI-driven lifelong learning companion to provide the necessary support and guidance to the students and with VR and AR interfaces to enhance the learning experience, to facilitate collaboration, modelling and problem solving. Beyond facilitating individual and group-oriented student activities, additional focus on supporting "classroom information management" and supervision by the teachers relying on intelligent analysis techniques, will be given. The Discovery Space classroom technology will be designed in such a way as to sustain teaching/learning/assessment related information flows beyond the use of single tools for specific purposes. In the next sections we zoom in on the virtues of remote and virtual laboratories and its combination and will then discuss the role of scaffolds.

2.8. Remote and virtual laboratories for inquiry learning

Do we need real, physical, laboratories for learning?

The first question we should state is if online labs can replace real, physical, laboratories. Real laboratories are used in education for a multitude of reasons. For example, they facilitate the understanding of scientific concepts and increase students' interest and motivation. Additional reasons include awareness of safety procedures, and learning how to use humans' senses for observations, learning from failures and learning to work in teams. As an advantage for physical laboratories, one can emphasize the role for "physicality" for acquiring conceptual knowledge since it would trigger additional brain activities and would enhance student motivation. However, studies that explicitly focused on the use of physical manipulatives do not find these advantages and in comparison, with virtual manipulatives the assumed advantages of physicality could not be found in [53]. Direct comparisons of the effects of physical and virtual laboratories on the acquisition of conceptual knowledge of the domain show that both approaches can be equally effective for learning but that in several cases virtual environments led to better results. Studies that found real and virtual laboratory experiments of equal effectiveness for acquiring conceptual knowledge are for example de Jong et al, 2018 [53]. Sotiriou et al, 2020 [52] who focused on the acquisition of inquiry skills, also found that simulated and real experiments were equally effective. Other work shows an advantage of virtual labs over real laboratories: Chang et al. [54] compared students who worked with a physical optics laboratory with students learning with simulations, Huppert et al. [55], Finkelstein, et al. [56], and Bell and Trundle [57]. Overall, we can conclude that the literature supports the idea that remote and virtual (online) labs can replace direct (or face-to-face) access to real physical laboratories.

The distinctive virtues of remote and virtual labs

The fact that physicality is not relevant for learning makes that remote laboratories can be used instead of real physical labs. *Remotely-operated educational labs* ("remote labs") provide students with the opportunity to collect data from a real physical laboratory setup, including real equipment, from remote locations. As an alternative there are *virtual labs* that *simulate* the real equipment. Remote and virtual labs both have specific advantages for learning. The first advantage of remote labs is that they do not mimic the real lab, but students operate on real equipment. Remote labs thus give a more realistic view on scientific practice, including practical aspects such as occupied equipment etc. It, therefore, also give students a more realistic view on real lab work. Another advantage of remote labs is that measurement errors are present by nature, whereas in virtual environments measurement errors are often ignored. Competency in a domain includes knowledge that measurement errors (of different kinds) exist and how to deal with them. The reading of instruments in a virtual environment, for example, (with even a possibility to zoom in) is by nature easier than reading real instruments. de Jong et al. [46] showed that knowledge about measurement errors that is acquired outside a laboratory context doesn't easily transfer to the students' actions in a physical laboratory which suggests that real laboratory experiences may be important. Learning, however, is not all about cognitive challenges and outcomes; also, enthusiasm and engagement play a role. Compared to research on cognitive outcomes results on motivational aspects of online and real labs is scarce but there are indications that real and remote labs lead to higher student motivation than simulated labs. Concerning the ease of experimentation, the advantages go in the direction of virtual labs. In virtual laboratories students can experiment without any costs and can more easily and repeatedly experiment so that ideas can be quickly tested and evaluated. Another advantage for virtual laboratories is that reality can be adapted to serve the learning process. Reality can both be simplified by taking out details (and thus lowering fidelity) or be "augmented" by adding specific features to reality (such as adding vectors to moving objects). Lowering fidelity means that the requirements on students are less severe which may add learning. Augmenting reality means that concepts that are not visible for students in the physical laboratory now become visible.

In conclusion, remote and virtual labs both have their specific virtues to bring to the learning situation; each of them also focusing on partly overlapping but also different learning goals. Our next exploration is how to potentially combine remote and virtual labs.

The best of both worlds: Remote labs in combination with virtual experimentation facilities

Since remote labs are offered over electronically, remote labs already offer some of the advantages of virtual labs in the sense that remote labs can be extended by augmentations and cognitive scaffolds, thus gaining some of the evident advantages of virtual labs. However, also in remote labs, experimentation is as time consuming as in real labs and, therefore, recent research started to develop and investigate combinations and sequences of the two. There are different possibilities here: blending and alternating both modes for the same or different contents. Blending means that characteristics of virtual labs, such as augmentations, are added to remote labs. Most of the work, however, has been on placing both versions in order and most of those studies showed that a virtual lab preceding a real (or in our case) remote lab is advantageous for learning. From a more cognitive point of view there are indications that the combination works because students must compare different types of representations. De Jong at al. [46] report a study in which they videotaped students who constructed electrical circuits only in a simulated environments with students who first made this virtual construction and then made the same circuit in reality. These video data made clear that students in the combined condition profited from the fact that they had to compare two representations that sometimes differed and had to go into abstract reasoning to explain these differences. A similar finding was reported by Sotiriou et al. [44] who found that offering both abstract and concrete representations in a simulation helped the student understand the principle behind the simulation. In this study it appeared that students who moved from a concrete to an idealized simulation outperformed other students on immediate and transfer test. In Discovery Space we will search for different ways to combine remote and virtual experimentation facilities. In any case, both remote and virtual labs need scaffolds to function effectively (see Section 4).

The role of scaffolds in inquiry learning with online labs

Scaffolding refers to support (dedicated software tools) that helps students with tasks or parts of a task that they cannot complete on their own. Scaffolds aim at the different learning processes that constitute inquiry learning. We can also scaffold the complete process by having student work with an inquiry cycle. Different types of structuring and scaffolds and their effects on knowledge acquisition have been overviewed in several studies. In any case meta-analyses [44] show that inquiry learning is only productive when the inquiry process is structured and scaffolded.

While using the Discovery Space Exploratory Learning Environment students will be encouraged to actively construct their own knowledge by exploring the learning environment and making connections with their existing knowledge schema. The role of AI will be to minimize the cognitive overload that is often associated with exploratory learning by providing automated guidance and feedback, based on knowledge tracing and machine learning. This feedback addresses misconceptions and proposes alternative approaches, to support the student while they are performing the experimental tasks. The AI-driven lifelong learning companion will support students to develop their learning paths that will provide structure to the student experience and thus allow each single person to pursue goals that require extended engagement or persistence across multiple contexts and learning opportunities. The role of teachers in such an exploratory learning setting is that of a "facilitator", or "orchestrator" of the learning process. This role would be relatively easy in one-to-one student-tutor interaction but scaling it up to the number of students present in a typical classroom poses several challenges. Given the open-ended nature of the tasks that the students are working on, it consists of a major challenge for the teachers to know which students are making progress, which are off-task, and which are in difficulty and in need of additional support. Such tools could empower teachers to provide evidence of students deeper learning, even in a context that is less subject to formal assessment, and to engage in their inquiry into more conceptual student learning.

Inquiry learning in Exploratory Learning Environments

There is a wealth of learning sciences literature about support for **inquiry learning in Exploratory Learning Environments** and more specifically in virtual labs. Here is list of the advantages such environments hold: The first is that following a scientific inquiry cycle possibly includes **encountering a cognitive conflict** between existing ideas and data that come from experiments. Based on such conflicts, students would then be stimulated to adapt their existing knowledge. This theoretical notion is closely related to the cognitive theories of schema development and adaptation. A second theoretical notion underlying the impetus for science learning is that online labs and accompanying simulations often use **multiple representations**. These different representations (graphs, animations, equations, tables, etc.) are dynamic and must be connected by students, which leads to processes of knowledge abstraction, as also explained by Mayer's multimedia theory [58]. A third underlying principle is that in the virtual lab environment **students oversee their own learning process**, which, according to theories of social learning, leads to higher motivation and especially to intrinsic motivation [59], while the students get control over the learning process by planning, monitoring, and reflecting about it. In this way, virtual labs also support self-regulated learning [60]. A fourth relevant theoretical approach is **constructionism** [61]. According to this theory, students learn through the process of identifying and representing the components that comprise a phenomenon. These components include objects (e.g., particles), processes (e.g., free fall), entities (e.g., acceleration), and interactions (e.g., how entities interact with objects or processes). In other words, the learner strips down the phenomenon into its components (an analysis process) and then builds up the phenomenon in a modeling environment (a synthesis process). However, the underlying premises behind each of these approaches could be overly optimistic; for example, sometimes students do not adapt their knowledge in response to anomalous data or they fail to connect representations [62]. In these cases, **instructional support is needed for successful learning**. Developing the technology to support effective learning in exploratory environments still faces several significant challenges. Such an approach requires the adoption of AI platforms and data-based learning analytics as key technologies in building integrated lifelong learning systems to enable personalized learning anytime, anywhere and for every student. We need to exploit the potential of AI to enable flexible learning pathways and the accumulation, recognition, certification and transfer of individual learning outcomes. Allowing students to demonstrate their competencies while they learn is advantageous, but how this might be achieved without continuous monitoring – i.e. surveillance – is less clear. Such monitoring involves also many ethical concerns.

3. Focus on the development of problem-solving skills

The core skills from which Deeper Learning consists of were extensively described and discussed in the previous section. The question that arises now is whether such competencies can be assessed during the instruction and how. The fact is that traditional assessment approaches based on questionnaires are not in line with the innovative approaches described in the previous section. Considering the case of problem-solving competency, it can be understood that measuring such a skill is a quite demanding task. It requires effort on structuring the tasks or the challenges in a way that allow the student to make use and develop his/her related skills. Our hypothesis in the framework of the Discovery Space project is that AI is an indispensable tool to achieve this goal, as it can spot the student's strength and weakness in problem-solving related tasks in real-time. In this section we will describe the model which could be used to assess the students' problem-solving skills while they are working with virtual and remote labs.

3.1. The problem-solving competence

Starting from the definition of problem-solving as it can be found in PISA 2012 [7]: "*Problem solving competence is an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen.*" The previous considers an individual working alone to resolve a problem, but as has been stated in PISA 2015 [63] students who are transitioning form school to workforce are expected to be able to collaborate with others, thus they should have already developed collaborative problem-solving skills. Moreover, PISA 2015 [63] mentions that the assessment of the problem-solving competency of an individual is taking place within collaborative situations, thus we should refer to collaborative problem-solving, which involves an individual's cognitive processing towards the solution of a problem [63]. According to [63]: "*Collaborative problem-solving competence is the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution.*"

Our goal within the Discovery Space project is to design a process which will facilitate the assessment the students' problem-solving competency, by fully exploiting the advantages that AI has to offer towards this end. The AI agent should act as a learning companion who guides the student and helps him to develop his/her own problem-solving skills. For that reason, we have created a number of educational scenarios which are structured in a way that the problem-solving competence of the students can be both assessed and developed. Before moving to a detailed presentation and explanation of such a Discovery Space scenario, we are going to discuss here how such a model has been developed based on the above-mentioned definition, the conceptual dimensions which provide the frame for the assessment [7,63] and the processes towards the solution of a problem by an individual as mentioned in [7,63]. Furthermore, key collaborative skills recognized in [63] will be also discussed and then the model will be introduced. It is crucial to mention here that the results that will be obtained from the model are going to be used as input educational data for the training of the AI learning companion, developed within the framework of the project.

Starting from PSC, its assessment basis can be described with three conceptual dimensions, which are:

- The *problem context*: This is referring to setting of the problem, more specifically if it involves a technological device or not, as well as, the focus of the problem, thus if the problem is personal or social.

As the Discovery Space project is based on the development of an AI learning companion, the use of a technological device (computer, tablet) is necessary. Furthermore, Discovery Space will handle problem-cases from STEM, where the students are going to be asked to work as researchers, thus the focus of the problem can be identified as social.

- The *nature of the problem situation*: This is referring to the completeness of the problem information. If all the necessary information has been given upon the problem's presentation, then such a situation is recognized as a static situation, otherwise, if exploration is necessary to obtain new information towards the solution of the problem, then this is referred to as an interactive situation. We note here that exploration is a crucial part of the Discovery Space project, as we aim to build an exploratory learning environment (ELE), which will facilitate students' inquiry-based learning. Thus, the project will handle interactive problem situations.
- The *problem-solving processes*: The final dimension in PSC has to do with the processes employed towards the solution of a problem. PISA 2012 and PISA 2015 [7,63] identified four cognitive processes for the achievement of this goal, which are:
    - *Exploring and understanding*: The problem situation is explored by the problem solver, who is collecting the given information and identifies obstacles towards the solution of the problem.
    - *Representing and formulating*: This strategy is used for the construction of a coherent mental representation of the problem, while the problem solver is formulating a hypothesis after relevant factors/parameters of the problem have been identified.
    - *Planning and executing*: A plan is set which eventually will lead to the solution of the problem. Specific goals must be defined and the steps towards the achievement of these goals need to be understood by the problem solver. Accordingly, the problem solver proceeds to the execution of the plan, making sure that the appropriate steps are taken in the correct way and order.
    - *Monitoring and reflecting*: The problem solver is monitoring the execution of the plan and is constantly trying to understand the obtained results. The problem solver needs to compare the acquired results with the hypothesis made before and either validate it or reject it, reaching a solution for the problem. Reflection on the process followed so far is necessary for the problem solver to communicate his/her progress in a clear and concise manner.

As noted in [7,63], the above-mentioned problem-solving processes involve several reasoning skills. Such reasoning skills can be inductive, deductive, quantitative, correlational, analogical, combinatorial, etc. It is also noted that these reasoning skills are not mutually exclusive and problem solvers are employing them to collect information and test hypotheses.

All the above-mentioned are incorporated into collaborative problem-solving. As education is shifting towards inquiry-based and project-based learning, groups of students need to work together to solve problems and achieve set goals. Thus, CPS is a critical 21st century skill that students need to develop to be fully equipped to handle future challenges. According to PISA 2015 [58], three core collaborative problem-solving partial abilities are:

- *Establishing and maintaining shared understanding*: This refers to the ability of identifying mutual knowledge among the group members and establishing common goals towards the solution of the problem. Group members should communicate with each other to make clear what each member knows, what is the overall status of the group and which actions should be taken next.

- *Taking appropriate action to solve the problem*: This skill is related to the students' ability to recognize the optimal CPS activities that solve the problem. The performed actions include debates and exchange of arguments between group members to clarify and communicate complex information and the transmission of everyone's knowledge to the whole group. This skill distinguishes a competent collaborative problem solver, as this person can engage productively with other group members, troubleshoot and evaluate the plans of the group.
- *Establishing and maintaining team organization*: This skill refers to the students' ability to understand the role that fits them best within the group, follow the rules set by the group and find effective ways to deal with problems that might emerge. Furthermore, in what concerns this skill, a student who is a competent collaborative problem solver might either act as a strong leader under certain circumstances dictating for such an action or step back in a different case.

PISA 2015 [63] clearly states that the above-mentioned skills emerge because of the combination of individual and collaborating problem-solving skills, thus an assessment of CPS skills contains valuable information about an individual's problem-solving skills. For the purposes of the Discovery Space project, the AI learning companion is expected to play the role of a second participant beyond the student, while a more ambitious goal of the project is the creation of a second agent, who will create "noise" to simulate more realistic group conditions.

Once CPS has been explained, the way that it should be incorporated into the implementation of the Discovery Space project should be discussed. At this point we need to remind the reader that the development of the Deeper Learning Classroom, where inquiry-based learning (IBL) and problem-based learning (PBL) will be prioritized over traditional learning approaches, is in the core of the Discovery Space project. In what concerns IBL, according to Kaselman [64], students create their own knowledge by following the same methods and practices as professional scientists do. The advantages of IBL have been discussed in numerous works [65,66], while it has also been defined in the literature [67] as a discovery process where the learner is formulating hypotheses and performs experiments to validate them or reject them, creating in this way new knowledge, as it is the case for the global scientific community.

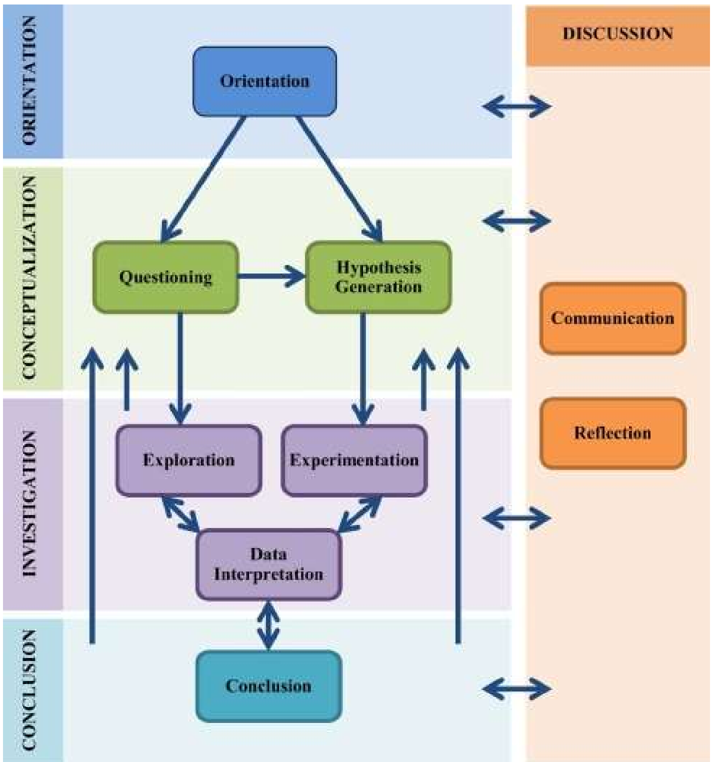


Figure 3: Inquiry-based framework showing the different phases of the process [67].

One of the main reasons for the efficiency of IBL is that it breaks a problem into smaller problems, which are easier to be solved, and then composes the general solution from the solutions of the different sub-problems.

Each of these sub-problems can be seen as a step or a phase of an inquiry cycle, which is not strictly defined [67]. Bybee and co-workers [68], for example, have described in their work the 5E inquiry cycle, with the following stages, Engagement, Exploration, Explanation, Elaboration and Evaluation, while White and Frederisken [69] have also identified five phases calling them, Question, Predict, Experiment, Model and Apply. A detailed description of the different inquiry phases and the different terms used in literature has been given by Pedaste and coworkers [67].

As has been stated in Ref. [67], and we also mention here, IBL is not a predefined process, thus the connections between the different phases and *the names given to them could vary*. In our approach which is described in the following parts of this document, we mention the names that we have chosen for the different phases of a Discovery Space scenario and present our assessment model for measuring a student's PSC. Furthermore, such models, while they are well documented in theory are not applicable in the real classroom settings as one must consider the school organizational issues, and more specifically the traditional 45min lesson duration and the different levels of the students as not all of them are able to achieve the same level of understanding at the same time. In fact, it is not possible to apply such a complex instruction scheme in a real school environment. In the framework of Discovery Space project, we are planning to make a first step towards the creation of deeper learning conditions in a real classroom environment with the support of a) the virtual and remote labs (to offer opportunities for personalized experimentation and reflection) and b) the presence of a learning companion (AI-enabled, to offer the necessary scaffolds according to the level of understanding of each student). To achieve that a real-time assessment process is needed to define the level of understanding of each student involved in the experimentation.

3.2. The Discovery Space assessment model

After describing the collaborative problem-solving and the stages of inquiry-based learning, the assessment model that will be used is described. The structure of a Discovery Space implementation scenario (simulation of the deeper learning classroom design) will be discussed in the following section, where a complete scenario will be presented. Before doing so, we are going to explain the phases of a Discovery Space scenario by simplifying the complex instructional approach that is proposed in theory [Figure 3]. In [67] one can discern the path Orientation, Hypothesis generation, Experimentation, Data interpretation and Conclusion. This path fits well the way that we want to structure a scenario in experimentation in science lessons. We also adopt such a five-phases model [68,69] and we define the following phases (Orientation has been renamed to Engagement and Conclusion to Reflection), which are:

1. **Engagement**: A phenomenon is presented to the students through an appropriate demonstration, to spark their interest and motivate them to work on its understanding.
2. **Hypothesis**: The students are asked to make a hypothesis to explain the phenomenon by identifying the main parameters for its explanation.
3. **Experiment**: At this stage the students are performing experimental work, using either a virtual or a remote lab, in order to see the effect that each identified parameter has on the phenomenon under discussion.
4. **Data analysis**: The sets of data collected at the previous phase are now analyzed and conclusions are drawn, which either reject or validate the hypothesis made at the second step above.
5. **Reflection**: At this stage the students reflect on what they have learned so far, while they are presented with a series of more demanding questions aiming to test how confident they are on their understanding.

Each of the above-mentioned phases of the scenario relates to one of the problem-solving processes [7,63] discussed before. During each phase the student deals with several challenges and according to his/her performance, either continues to the next phase or must perform more tasks before moving on forward. The model proposed here considers the student's performance at each phase of the scenario, but in addition to that a weighting factor has been attributed at each phase of the scenario. The different weighting factors can be seen on Table 3, and they are in accordance with Ref. [63].

Table 3: The weighting factors for the different phases of a Discovery Space scenario. The performance of a student at each phase will be multiplied by the respective factor to assess the overall student's PSC.

Problem-solving process	Scenario phase	Weighting factor
Exploring and understanding	*Engagement*	$C_{Eng.}$ 20%
Representing and formulating	*Hypothesis*	C_H 20%
Planning and executing	*Experiment*	$C_{Exp.}$ 30%
Monitoring and reflecting	*Data analysis*	C_{DA} 15%
	Reflection	C_R 15%
		100%

Considering a function $f_{phas}\ (x_i)$, where x_i are scores of the answers to the tasks assigned to the student within this phase, then:

$$f_{phas} = \frac{x_1 + x_2 + \cdots + x_N}{N},$$

Accordingly, based on the weighting factors collated on Table 3, we get:

$$f_{PSC}(x_{Eng.}, x_H, x_{Exp.}, x_{DA}, x_R) = C_{Eng.} \times f_{Eng.}(x_{Eng.}) + C_H \times f_H(x_H) + C_{Exp.} \times f_{Exp.}(x_{Exp.}) + C_{DA} \times f_{DA}(x_{DA}) + C_R \times f_R(x_R),$$

where $\boldsymbol{f_{PSC}}$ is a measure of the students' PSC and the arguments of the function refer to a set of answers within the phase. At this point we need to stress that the previously described model will have to be revisited and further optimized, as different parameters (students' scores, weighting factors, students' scores at the different phases) could be used as input data to train the AI learning companion to identify learning patterns, so that it can design learning paths addressing each student's needs. In what concerns the scores of the different provided answers to a question, three different values will be given, as shown on Table 4.

Table 4: The scores of the answers and the respective level of understanding

Score of the answer	Level of understanding
1	Low
2	Moderate
3	High

As an example, consider the engagement phase, with three questions within it and a student who has $x_{Eng.} = (2,1,3)$, then according to the previous, for this student the resulting level for the phase will be $f_{Eng.} = 2$ and this will have to be multiplied with the relative weighting factor. According to their answers in a specific phase, students could be categorized into three different levels, as shown on Table 5.

Table 5: The different levels of performances of students according to their scores in phase

Score	Level
1.00 - 1.49	Low
1.50 - 2.49	Moderate
2.50 - 3.00	High

4. The Discovery Space scenarios as means towards the development of deeper learning

In this section, we will demonstrate how PSC could be assessed and further developed through the Discovery Space scenarios by presenting an actual scenario from the field of Physics, concerning the simple pendulum. Emphasis is given on the role that the AI learning companion plays, as it guides the students throughout the inquiry process, providing them with feedback targeting at their specific misconceptions, helping them in this way to develop an in depth understanding of the subject.

The structure of a scenario, as has already been mentioned in the previous section, consists of five distinct phases (see Section 3.2). Each phase is focusing on specific partial ability of PSC. According to PISA 2012 and PISA 2015 [7,63] being able to evoke previously acquired knowledge is not enough for the solution of a new problem. Instead, the already existing knowledge should be combined with new knowledge which will be obtained by probing the different aspects of the problem. The workflow of the inquiry process (scenario) is shown in Figure 4. Students who demonstrate deeper understanding of the phenomena under study will follow a different learning path, that will include more complex tasks and challenges. Students who demonstrate moderate understanding will follow another learning path with scaffolds to improve their understanding. Students who are demonstrating lower levels of understanding of the phenomenon under study will need to get involved in additional activities (learning cycle: concrete learning experience (feeling), reflective observation (observing), abstract conceptualization (thinking), and active experimentation (doing)) – including simulations and augmentations that are available– that could possibly facilitate the deeper understanding of the experiment and the phenomenon under study.

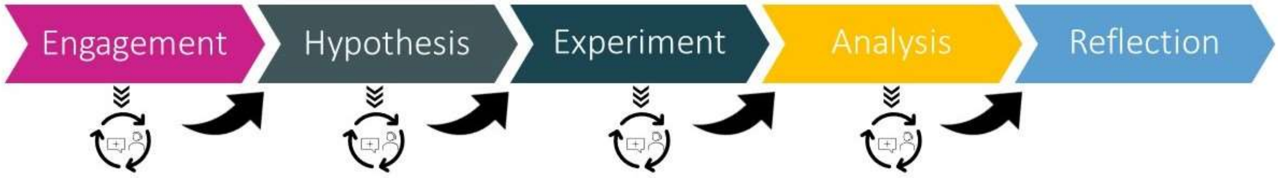
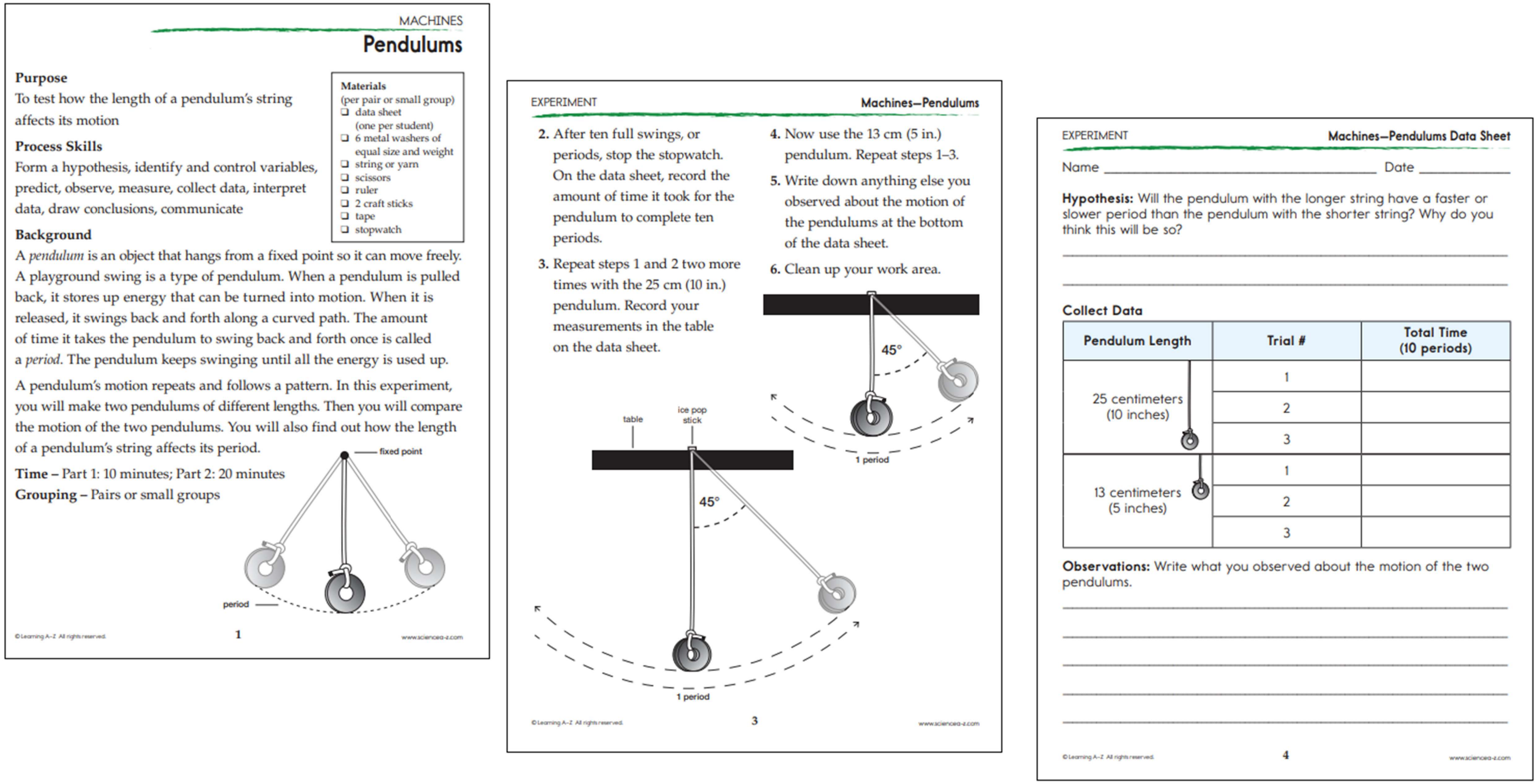


Figure 4: The workflow of an inquiry-based scenario. The scenario consists of five different phases, while students who are demonstrating lower level of understanding are receiving additional scaffolds by the AI learning companion. This is shown here as exiting the phase and entering a loop before moving forward, demonstrating the learning cycle approach that is introduced.

4.1. Indicative scenario: The simple pendulum

In this subsection an illustrative example on how the AI learning companion could facilitate the inquiry process. The scenario concerns the case of the simple pendulum, a common topic in the introductory lessons in the lower secondary school Physics curricula. At this level the pendulum is used as a device for measuring the time. The accuracy of the measurements and the definition of the parameters that could affect the results of measurements are the focus points of the intervention. The aim of the experiment is the measurement of the Period of the pendulum and the identification of its dependence (or not) on a number of parameters (mass of the pendulum, length of the pendulum). The pendulum is introduced with a simple demonstration, and accordingly students are asked to define the optimal (most accurate) process (experiment) to measure the period T of the pendulum.



MACHINES
Pendulums

Purpose
To test how the length of a pendulum's string affects its motion

Process Skills
Form a hypothesis, identify and control variables, predict, observe, measure, collect data, interpret data, draw conclusions, communicate

Materials
(per pair or small group)
- data sheet (one per student)
- 6 metal washers of equal size and weight
- string or yarn
- scissors
- ruler
- 2 craft sticks
- tape
- stopwatch

Background
A *pendulum* is an object that hangs from a fixed point so it can move freely. A playground swing is a type of pendulum. When a pendulum is pulled back, it stores up energy that can be turned into motion. When it is released, it swings back and forth along a curved path. The amount of time it takes the pendulum to swing back and forth once is called a *period*. The pendulum keeps swinging until all the energy is used up.

A pendulum's motion repeats and follows a pattern. In this experiment, you will make two pendulums of different lengths. Then you will compare the motion of the two pendulums. You will also find out how the length of a pendulum's string affects its period.

Time – Part 1: 10 minutes; Part 2: 20 minutes
Grouping – Pairs or small groups

fixed point
period

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EXPERIMENT — Machines–Pendulums

2. After ten full swings, or periods, stop the stopwatch. On the data sheet, record the amount of time it took for the pendulum to complete ten periods.
3. Repeat steps 1 and 2 two more times with the 25 cm (10 in.) pendulum. Record your measurements in the table on the data sheet.
4. Now use the 13 cm (5 in.) pendulum. Repeat steps 1–3.
5. Write down anything else you observed about the motion of the pendulums at the bottom of the data sheet.
6. Clean up your work area.

table
ice pop stick
45°
1 period
45°
1 period

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EXPERIMENT — Machines–Pendulums Data Sheet

Name ____________ Date ______

Hypothesis: Will the pendulum with the longer string have a faster or slower period than the pendulum with the shorter string? Why do you think this will be so?

Collect Data

Pendulum Length	Trial #	Total Time (10 periods)
25 centimeters (10 inches)	1	
	2	
	3	
13 centimeters (5 inches)	1	
	2	
	3	

Observations: Write what you observed about the motion of the two pendulums.

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Figure 5: The study of the simple Pendulum is a very common topic in the Physics curricula. The Figure presents indicative pages of school textbooks that include worksheets to document the students' findings. The study of the Pendulum is used to introduce the concept of time and the periodic phenomena. Students will need to perform several measurements and to assess their accuracy. Furthermore, through the realization of the measurements, students will need to explore the dependance of their period of the pendulum's motion on its mass and on its length. The overall duration of this activity varies from 3 to 5 didactical hours. In Discovery Space we will enrich this common educational activity with a number of challenges where the students will interact with the AI learning companion. Based on the students reactions and responses the AI learning companion will guide the students during the inquiry process. Students who demonstrate deeper understanding of the phenomena under study will follow a different learning path, that will include more complex tasks. Students who demonstrate moderate understanding will follow different learning paths with scaffolds to improve their understanding. Students who are demonstrating lower levels of understanding of the phenomenon under study will need to get involved in additional activities (learning cycle) – including simulations and augmentations – that could possibly facilitate their conceptual change.

Exploring and understanding

The challenge is presented in the following way:

Q1: To achieve the most accurate measurement of the period of the pendulum:

A. **I must measure the total time (t) of many oscillations (N) and then calculate the average time (period) for one oscillation T=t/N. (3p)**
B. **I must measure the period Ti of each of many oscillations (N) and then calculate the average time $T = (T_1 + \cdots + T_N)/N$. (2p)**
C. **One measurement is enough. (1p)**

The challenge for the students here is to identify the physical meaning behind mathematical operations and be able to understand the differences behind options A and B. The source of errors, which are introduced in the measurements, should be identified by the students. According to the given answers, different learning paths can be drawn. Students choosing the option A are identified as (potential) high performing students, since they can understand that the error source is on the reflexes of the experimenter as he/she performs the measurement. Students that give as answers options B and C above are identified as (potential) moderate and low performers, respectively, and further actions are required, so they can understand why their options will not minimize the error in the measurement of the period. The final decision for the level of the student will be made at the end of each phase, as it must be based to a series of responses to the challenges set by the AI learning companion. Students who demonstrate moderate and low levels of understanding will be asked to use the virtual lab (https://phet.colorado.edu/sims/html/pendulum-lab/latest/pendulum-lab_all.html) [70] and they will be involved in a number of experiments with it. This will offer them further time for experimentation in a controlled environment and will provide evidence of their exact level of understanding the key concepts.

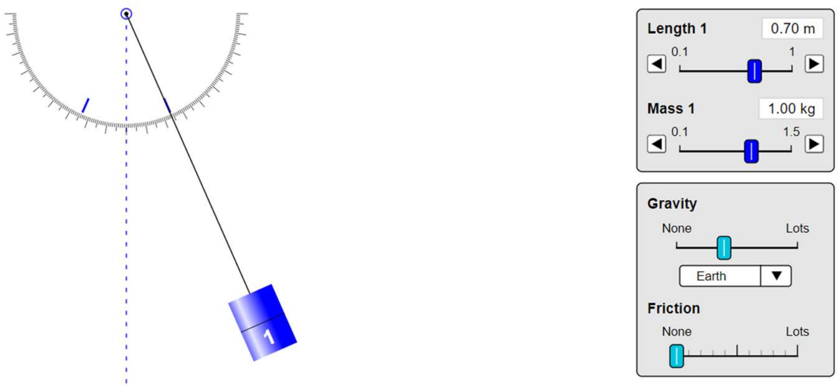


Figure 6: A virtual lab (see Ref. [70]) used for the students to measure the period T and perform experiments to identify the main parameters determining the pendulum's period.

After they become familiar with the lab, they must perform the following actions (the orange color indicates that these actions are addressing low and moderate performers) and then react to a set of challenges:

- **For a rope length of L= 0.70 m and a mass of 1 kg try to measure the period of a complete oscillation.**
- **Repeat the above process but this time try to measure the period of a complete oscillation four times.**
- **Compare your results with those of your classmates. Which is the source of deviations?**

By comparing their results and discussing the different values of the measured period, students are engaging in a process where they share understanding and effort to solve a problem. Moreover, as they start conducting experimental work, students start to develop an academic mindset, dictating to put any hypotheses they make into the test. Once they have performed the actions mentioned above, low and moderate performers in Q1 will need to react to a new series of challenges:

Q1a: During the experiment, what causes the inaccuracy in the measurement of the period of the pendulum?

A. Your reflexes when operating the stopwatch, mainly when starting the clock.
B. Your reflexes when operating the stopwatch, both when starting the clock and when you stop it.
C. You should be more careful with your measurements next time.

Q1b: We propose you to count the total time of more pendulum oscillations and divide it by the number of oscillations. Which measurement is going to be the most accurate one?

A. By measuring the time of 1 oscillation.
B. By measuring the time of 50 oscillations.
C. By measuring the time of 5 oscillations.

Students choosing options A or C in questions Q1a and Q1b will need to repeat their measurements and if they still have difficulties, then the learning companion will explain to them the process of getting the most accurate result (see Figure 7).

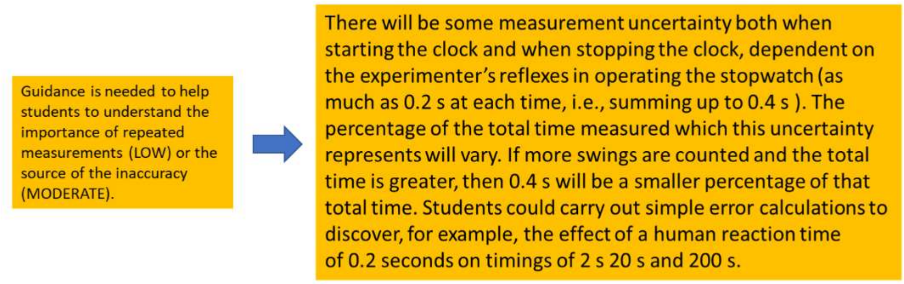


Figure 7: The AI learning companion will provide the necessary explanation at the end of the learning cycle to facilitate the continuation of the inquiry process.

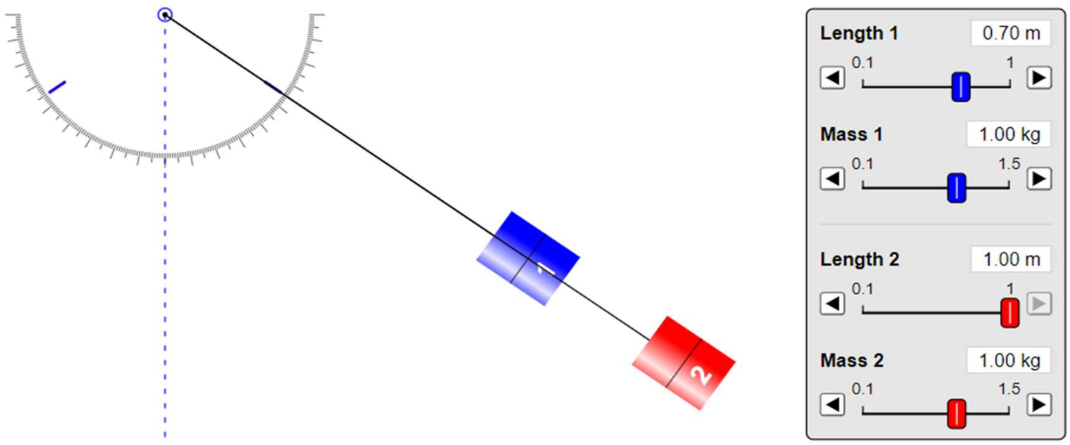


Figure 8: Two pendula with different rope lengths and same mass [65]. Students will need to answer which one swings faster. In this way reasoning skills are employed during the problem-solving process, while they start decomposing the problem to its parameters.

Accordingly, all students are presented with two different cases where there are two pendula. In the first case they have the same mass but different lengths and in the second case the same length but different masses. The former case is shown in Figure 8, followed by Q2 and the latter in Figure 9, followed by Q3.

Q2: Which pendulum swings faster if there is no friction?

- **A. They go the same speed. (1p)**
- **B. 1 is faster. (3p)**
- **C. 2 is faster. (1p)**

The main goal of Q2 and Q3 is for the students to start identifying the main parameters from which the problem consists of. In addition, these questions are preparing the students for the following phase of the scenario (hypothesis), where they will have to use their inductive skills to reply on questions which are linking directly the different parameters (length, mass) with the pendulum's period. Furthermore, the answers given by the students at this phase will be used by the AI learning companion, in combination with the answers that will be provided in phase 2, to (re)design the optimal learning path for each student.

Representing and formulating

Moving on to the hypothesis phase, students will need to represent and formulate. The relative parameters should have been identified, yet their effect on the period is not fully clarified to this point, thus the following questions are testing the student's skills towards this direction. The first (Q4) concerns the length of the pendulum and the second (Q5) is about the effect of the bob mass.

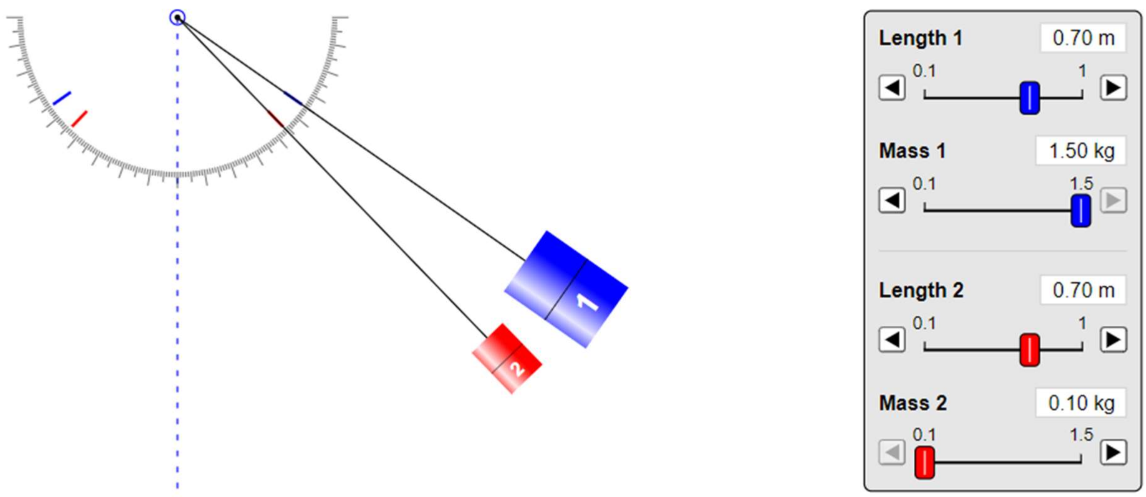


Figure 9: Two pendula with the same rope length and different masses [65]. Students will need to identify whether the mass has any effect on the period of the pendulum.

Q3: Which one swings faster if there is no friction?

- **A. They go the same speed. (3p)**
- **B. 1 is faster. (1p)**
- **C. 2 is faster. (1p)**

Q4: What can you say about the length of the rope?

A. Does not affect the speed of the pendulum. (1p)
B. Shorter length means higher speed. (3p)
C. Shorter length means lower speed. (1p)

Q5: What can you say about the bob-mass?
A. It does not affect the speed of the pendulum. (3p)
B. Smaller mass means higher speed. (1p)
C. Smaller mass means lower speed. (1p)

Representation skills should be employed here, and the students start creating rough models connecting the length and mass with the period. High achievers should identify that the mass has no effect on the period of the pendulum. It is worth noting that both questions ask about the speed of the pendulum not the period, thus the connection between the two needs to be clearly understood. Such a process is developing students' critical thinking as they must make a hypothesis based on the two parameters that they can vary. Returning to the discussion of the pendulum scenario, students with low performance are going to perform a series of measurements and answer questions, as presented below (the red color refers to low performers).

Measure the period for three different pendula, using the virtual lab, and complete the table.

L (m)	m (kg)	T (s)
1	0.5	
0.7	0.5	
0.7	1	

At this point the students are expected to be familiar with measuring the period of the pendulum. The teacher can validate that students who cannot create the appropriate model for the pendulum's period are now learning through the experiment. Whether or not students have reach to the right conclusions is tested with the following questions:

Q_{L1}: Compare the values of T1 and T2 (different length, same mass), what do you observe?
A. L1>L2 and T1>T2
B. L1>L2 and T1=T2
C. L1>L2 and T1<T2

Q_{L2}: Compare the values of T2 and T3 (same length, different mass), what do you observe?
A. m2<m3 and T3>T2
B. m2<m3 and T2=T3
C. m2<m3 and T3<T2

In the process described above, students follow a deductive path [71] to reject their mistaken hypothesis on the relationship between T, L, and m, after they have collected and analyzed data, while on the same time they need to follow an inductive pathway [71], where from their given observations they need to recognize patterns and consequently draw general conclusions. Guidance will be provided to moderate performers concerning the relationship between the pendulum's period, the frequency of the pendulum and its speed. Accordingly, they move to the next phase of the scenario, the experiment, in which high performers already are. By this point low and moderate achievers should already know that the period increases as the length increases.

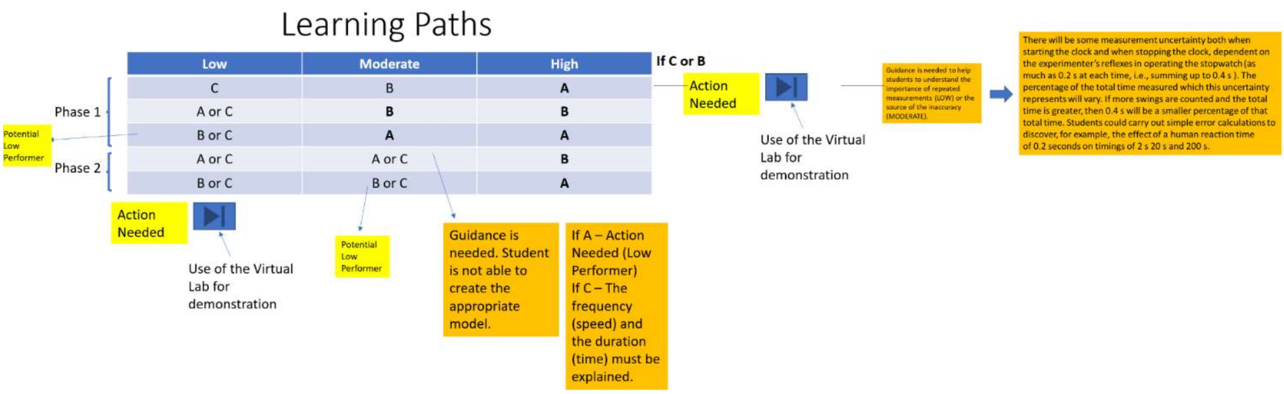


Figure 10: Based on the reactions of students a different educational path is assigned to them. The characterization of the student as low, moderate or high performer is not based on a single response to a challenge but is progressively constructed based on a series of reactions to different challenges that the student is facing in his or her educational path. For example, students who were not able to realize which option is minimizing the error in the estimation of the pendulum's period are only considered low performers only later in the process based on their reactions in the four challenges which follow the initial response.

Planning and executing

In this phase students are called to perform their own experiments. As mentioned earlier, some students (low performers) have already performed experimental work, thus, given the time constraints, this might be the end of the learning pathway for those students. According to the assessment model presented in the previous section, they will receive 1p for the questions in the phases that they did not perform. At this stage students are planning and executing experiments which should in principle validate their hypotheses from the previous phases. Deductive and quantitative reasoning skills are employed in this phase, while the way that students are performing the measurements is also important, as development of critical thinking is necessary to get the most accurate experimental results. Students should perform the experiment by *varying a single parameter each time*, thus they can clearly understand its effect on the pendulum's period. Small groups of students can be formed favoring collaborative problem-solving once again. Two different experiments are expected to take place, the first investigating the relationship between the period of the pendulum and its length and the second the relationship between the period of the pendulum and its mass.

Experiment 1: Design an experiment to check your hypothesis on the relationship between the pendulum's period and length. Could you reach to a reasonable conclusion if you vary both the length and the mass simultaneously.
Use the virtual lab for your experiment and fill the following table:

m	L	t (30 oscillations)	T

It must be noted that the AI learning companion will continuously monitor the students work. For example, in this experiment the learning companion will check if the students are performing the measurement of the period with the higher accuracy (measuring the total time of a number of oscillations and then divide by the number of oscillations as it was indicated in the first phase). In case that the students are not following the correct procedure a tip could be offered: *Think about how you would measure the period to achieve greater accuracy.*

After the students have completed the experimental procedure, once more they will need to answer a question and accordingly specific tasks will be given to them in case, they have not provided the correct answer. This is shown below:

Q6: Which one of the following do you observe according to your measurements?

A. **If the mass of the pendulum remains constant and its length increases, then its period decreases. (1p)**
B. **If the mass of the pendulum increases and its length increases, then its period decreases. (2p)**
C. **If the mass of the pendulum remains constant and its length decreases, then its period decreases. (3p)**

Results and actions:

- **If B then low performer: Repeat the experiment and keep the mass constant.**
- **If A then moderate performer: Repeat the experiment more carefully this time.**
- **If C then high performer: Move on to the next experiment.**

The second experiment is more demanding as students need to identify that the mass of the pendulum does not affect its period.

Experiment 2: Design an experiment to check your hypothesis about the relationship between the mass of the pendulum and its period.
Use the virtual lab to conduct your experiment and fill in the same table as in Experiment 1.

The learning companion will check again if the students are performing the measurement of the period with the higher accuracy (measuring the total time of a few oscillations and then divide by the number of oscillations as it was indicated in the first phase). In case that the students are not following the correct procedure a tip could be offered: *Think about how you would measure the period to achieve greater accuracy.* The learning companion could also highlight the importance of changing one parameter at the time while performing the experiment in case that the students are changing at the same time both with the following tip: *If we want to find the relation between two variables, we need to keep all the other variables constant. Which are the variables in this experiment?*

Monitoring and reflecting

As was the case before, a question about the outcome of the experiment is following, and accordingly there is a classification and actions to be performed at each level, as follows:

Q7: According to your measurements, which of the following statements is correct, about the relation between the mass of the pendulum and its period?

A. **If the mass of the pendulum increases and its length remains constant, then its period remains constant. (3p)**
B. **If the mass of the pendulum increases and its length increase, then its period increases. (2p)**
C. **If the mass of the pendulum and its length increase, then its period remains constant. (1p)**

Students who will select the options B or C will receive further guidance and support to realize the process of performing the experiment while modifying only one variable at the time. The provision of scaffolds at this point is based on the functionalities of the virtual lab that allows for such interventions. In a more advanced learning environment, the AI learning companion could be informed for the students' actions directly from the lab interface.

Encountering a cognitive conflict

For most of the students, the above-mentioned phases are expected to absorb all the available time allocated to the scenario. Nevertheless, very competent students are also expected to go relatively fast through phases 1-4 of the scenario and for that reason we are introducing a fifth phase (reflection), to challenge them more. In more detail, at this last phase the goal is to check how confident the students are in the knowledge that they have acquired so far and further clarify meanings that might still be unclear for them. At first, we revisit the mass of the pendulum.

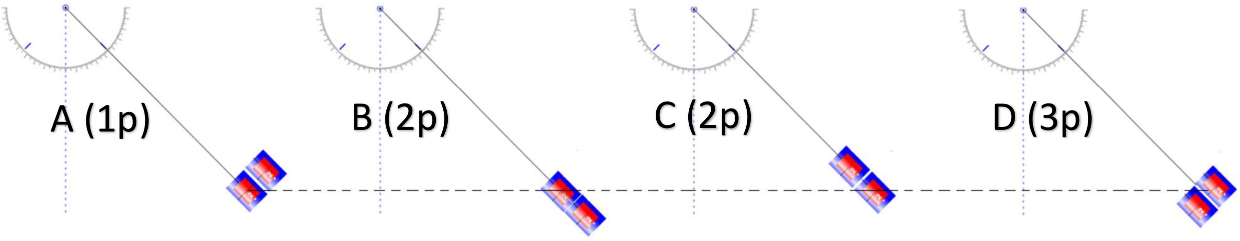
We want to assess students' critical thinking and deeper understanding on the influence of the mass on the pendulum's period, by leading them in purpose towards results which contradict their previous observations. Accordingly, students will need to identify subtle differences between the problem situation presented to them at this phase and the ones in the previous. In the following we discuss the specific example from the scenario.

Figure 11: The pendulum (remote lab) of LabsLand. It will be used by students who make it to the last phase of the scenario.

We use of the LabsLand pendulum [72] (remote lab, shown in Figure 11) for this purpose. Students have the option to increase the mass of the pendulum by adding mass on the top of the mass that is adopted to the pendulum. This is not the correct way to increase the mas of the pendulum as now the center of mass is displaced, and it is located higher.

We will take advantage of this mistake and we will support students to identify that by attaching the additional mass, the position of the center of mass is changing, which is equivalent to a change in the length of the rope, thus the period is affected.

Q8: So far, we have established that the mass of the pendulum does not affect its period. Suppose now that you need to hang a second mass from the pendulum. In your opinion, which is the best way to do that, out of the four shown in the image?



After the students have provided an answer, they are called to perform an experiment again, this time using the remote lab shown in Figure 11. The LabsLand pendulum [72] allows them to select how the second mass will be attached and then they can start timing the period of the "new" pendulum and test again if there is any dependence on the mass. A set of detailed instructions is also provided to the students, as described below:

Q9: Does the period of the pendulum depend on the suspended mass?
Instructions: Swing the pendulum at an angle of oscillation of 25˚ and determine the period of oscillation for the different masses selected. Measure the time corresponding to a total of 10 oscillations. Repeat this process twice and determine the average time. Then divide the total time by the number of oscillations and calculate the oscillation period. Present your results on a table.
Note: The results may vary depending on the angle of oscillation chosen and on the average time calculated.

Once the students have completed their measurements, they should obtain a table like the following one and then they will be provided with two answers for the question above (Q9):

	Mass	t (s) (10 oscillations)	T (s)
Experiment 1	M (initial value)	13,87	1,387
Experiment 2	M+m (m is placed on the top of M)	12,70	1,270
Experiment 3	M+m (m is placed under M)	14,74	1,474

A. **Oh! I made a mistake. The period depends on the mass. (1p)**
B. **My assumption was correct. The way that I am attaching the additional weight is crucial. The center of mass must remain to the same point. (3p)**

According to the answers given in the two questions of the reflection phase, the students are classified as follows:

LOW PERFORMER	MODERATE PERFORMER	HIGH PERFORMER
A	B or C	D
A	A	B

The reflection phase is indicative of the students deeper understanding as students are called to support the model that they have already created against actual experimental data which are indicating otherwise. Such an approach is in the core of the Discovery Space project, as it favors exploratory learning supported by remote and virtual labs, while students are mastering the academic content taught to them and are developing an academic mindset. The latter phase of the scenario is also indicative of the development of critical thinking, since the students are supporting their opinion with an argument rather than quit and admit they were mistaken without any further thought. Concluding the discussion about the pendulum scenario, a classification of the different learning paths, for the low, moderate and high performers is collated on Table 6.

The crucial role that the AI learning companion plays becomes obvious by looking on Table 6. It would have been impractical to write down all the possible outcomes of the multiple-choice questions and design a learning path for each one, yet by not doing so it means that the above classification is not including a vast number of combinations. For example, in which of the three categories a student who gave the following combinations of answers (A, C, C, B, A, C, C, C, B) belongs to? The learning companion though can be trained to recognize different learning patterns by accumulating more and more data and design a learning path accordingly, thus the above classification serves as a guide to the AI learning companion. It is worth noting again that the teacher can watch the students as they are going through the learning path, as the AI learning companion provides feedback at every time.

Table 6: An overall description of the paths of the low, moderate and high performers, according to their reactions to the challenges posed by the AI learning companion. In fact, here we are presenting the three reference paths. In the real classroom setting numerous paths will emerge as the reactions of the students will vary from the reference paths, moving from one level to the other.

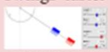
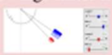
<table>
<tr><th>Question</th><th>LOW PERFORMER</th><th colspan="2">MODERATE PERFORMER</th><th>HIGH PERFORMER</th></tr>
<tr><td>1</td><td>C</td><td colspan="2">B</td><td>A</td></tr>
<tr><td>2</td><td>A or C</td><td colspan="2">B</td><td>B</td></tr>
<tr><td>3</td><td>B or C</td><td colspan="2">A</td><td>A</td></tr>
<tr><td>4</td><td>A or C</td><td>A or C</td><td>B</td><td>B</td></tr>
<tr><td>5</td><td>B or C</td><td>A</td><td>B or C</td><td>A</td></tr>
<tr><td>6</td><td>B</td><td colspan="2">A</td><td>C</td></tr>
<tr><td>7</td><td>B</td><td colspan="2">A</td><td>C</td></tr>
<tr><td>8</td><td>A</td><td colspan="2">B or C</td><td>D</td></tr>
<tr><td>9</td><td>A</td><td colspan="2">A</td><td>B</td></tr>
</table>

Our goal is the simultaneous development of deeper learning and the development of 21st century skills on one hand, with mastery of academic knowledge on the other. A crucial role towards the achievement of this goal play both the structure of the scenario, which should be built in a way that allows students to create new knowledge based on what they have been taught so far, as well as the AI learning companion. The latter will guide the student through the different phases of the scenario and provide targeted feedback addressing his/her specific misconceptions.

The scenario in a compact form, along with the different educational goals of each phase is shown on Table 7.

The learning paths for the high, moderate and low performers are shown in Figure 12, Figure 13 and in Figure 14, respectively. A more complicated scenario, dealing with a phenomenon from Quantum Physics, the photoelectric effect, has also been prepared for the purposes of the project. This scenario is addressing to senior year students, while the contradictions between classical and quantum physics offer an ideal situation for practicing critical thinking and understand how to use experimental data as a guide for creating new knowledge and eventually master academic content.

Table 7: The pendulum scenario in a nutshell. In the first column of the Table (yellow) presents the phase of the scenario while the second column (blue) presents the partial ability of the problem-solving competence that we are focusing on. The related challenges and the questions are shown in the third column (red). The educational objectives of each phase are presented in the fourth column (green).

Engagement	Exploring and understanding	**Q1**: To achieve the most accurate measurement of the period of the pendulum? **Q2**: Which pendulum swings faster if there is no friction?  **Q3**: Which pendulum swings faster if there is no friction? 	The problem that the students are called to explore is the pendulum itself. Students need to understand the physical meaning of the period and see its importance for measuring time. Students start to connect Mathematics with Physics. Q1 aims to check if they have understood which is the source of errors during the measurement. High performers have understood that errors are caused by the reflexes of the experimenter, as he/she operates the stopwatch, thus by choosing option A, such erros are minimized. Low performers need help to understand the importance of repeating a measurement and moderate performers need guidance to understand the source of inaccuracy. In addition, students start thinking which are the main parameters that determine the pendulum's period, in other words they decompose the system to identify its components. A constructionist approach is applied. Q2 and Q3 test how well students can identify the role of each parameter without having any previous knowledge about the pendulum.
Hypothesis	Representing and formulating	**Q4**: What can you say about the length of the rope? **Q5**: What can you say about the bob-mass?	Check if the students can identify the role of key parameters and formulate a correct hypothesis about the dependence of the period on the length and the mass. Check indirectly if the relation between the speed of the pendulum and its period is understood. Students need to employ correlational reasoning skills. HIGH perfromers in Q4 and Q5 have a correct representation of the phenomenon in mind. Check whether or not students with low or moderate performance in the previous phase can create a correct mental representation after using the virtual lab to conduct experimental work.
Experiment	Planning and executing	**Experiment 1**: Design an experiment to check your hypothesis on the relationship between the pendulum's period and length. Could you reach to a reasonable conclusion if you vary both the length and the mass simultaneously. **Experiment 2**: Design an experiment to check your hypothesis about the relationship between the mass of the pendulum and its period.	At this phase, clear goals should be set and plans should be executed to achieve them. The first goal is to clarify the relationship between the pendulum's period and its rope length. An appropriate experiment should be designed and accurate measurements will take place so that the dependence will be obvious in the results. The importance of the previous steps is becoming obvious now. Accordingly the students will need to investigate the dependence between the bob-mass and the pendulum's period. The process aims to assess how well the students can perform experiments and whether or not they can perform the experiment in a correct way, by varying a single parameter and not several, so they can see the impact of the specific parameter. It should also be perfectly clear which are the parameters to be varied.
Data analysis	Monitoring and reflecting	**Q6**: Which one of the following do you observe according to your measurements? **Q7**:According to your measurements, which of the following statements is correct, about the relation between the mass of the pendulum and its period?	Analyse the results obtained during the experimental procedure and check whether or not they validate or reject the hypothesis made at phase 2. Check for unexpected results, evaluate if additional information is necessary and employ either deductive or inductive reasoning skills to draw conclusions. No matter which their previous responses were, students with high performance at this stage demonstrate that they can correclty interpret experimental results and use them as a guide to create correct models. Students with low and moderate performance will need to repeat the experiment in the first case, or go through the hints provided in the experiment instructions to understand how the experiment can be performed better, in the latter case.
Reflection		**Q8**: So far, we have established that the mass of the pendulum does not affect its period. Suppose now that you need to hang a second mass from the pendulum. In your opinion, which is the best way to do that, out of the four shown in the image?  **Q9**: Does the period of the pendulum depend on the suspended mass?	The knowledge created by the students so far is challenged. At this phase students need to look back and think what they have learnt throughout the scenario. First the physical intuition of the students is checked by asking them how to attach an additional weight. Those who answer correctly this question demonstrate a good grasp of the pendulum's setup, as it is crucial to let the center of mass intact when attaching the additional weight. Then by presenting to them data which contradict their conclusions, we aim to test how confident they are on their knowledge. Students at this phase are reevaluating their understanding, reflecting on the different possible solutions of the problem and are employing multidimensional thinking. There is also a need for additional clarifications at this stage, as in order to answer correctly both questions Q8 and Q9 the meaning of center of mass should be clearly understood. Students who fail to answer these questions correctly will need to have the teacher explain to them in detail why it is crucial how we attach the additional weight so that the bob-mass has no effect on the pendulum's period.

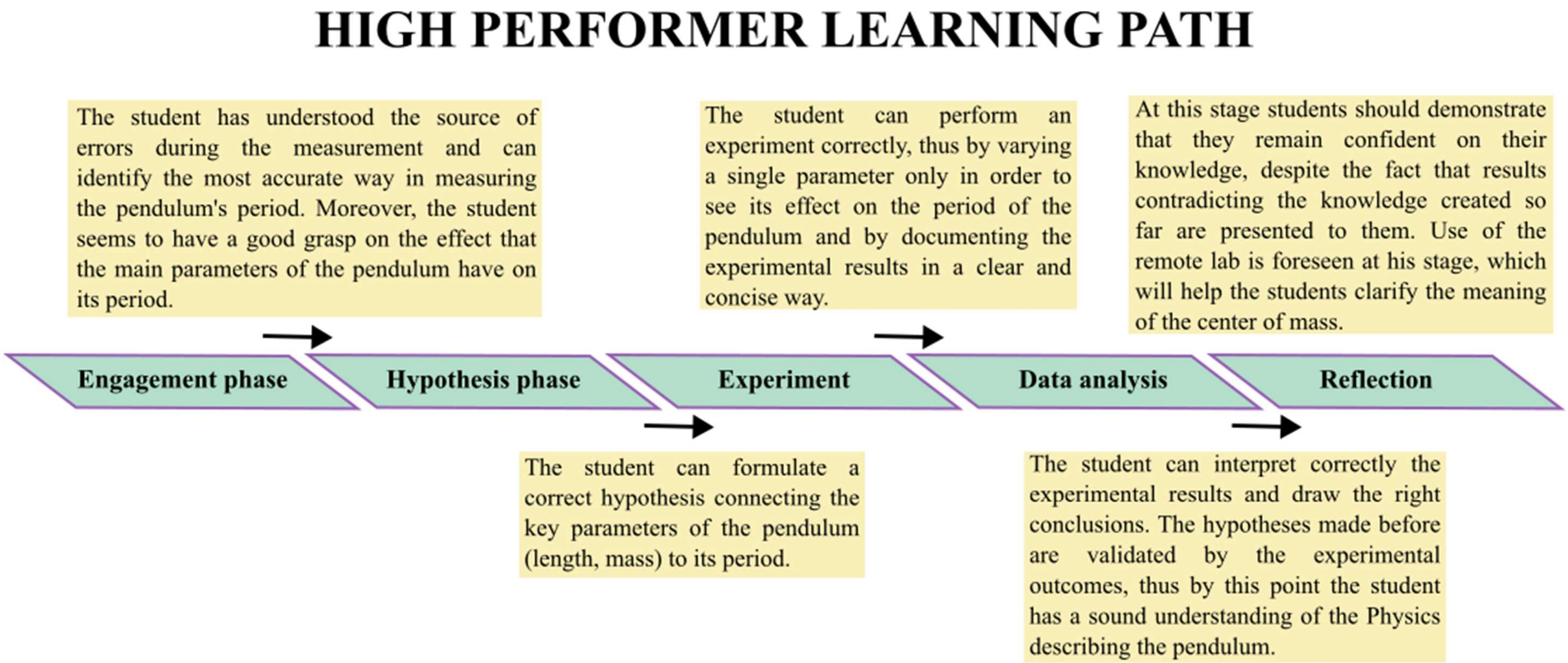


Figure 12: The learning path of a high performer. The different phases of the path are shown in the green parallelograms, while in the yellow boxes the learning goals that have been achieved by the student are mentioned. As it can be seen in the figure, the student will go through all the different phases of the scenario.

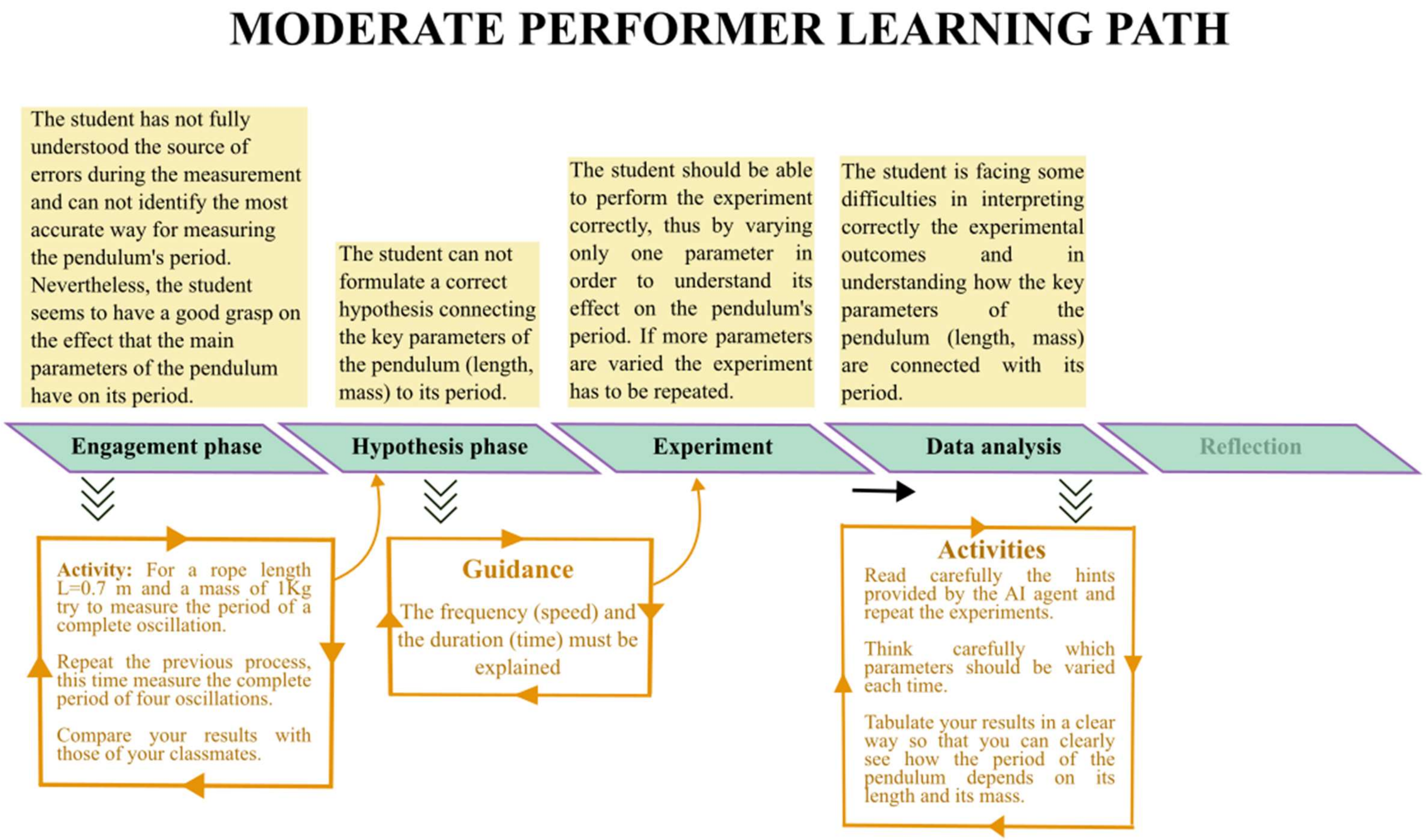


Figure 13: An indicative learning path for a moderate performer. In this case the AI learning companion provides guidance to the student before he/she moves forward, as the results indicate that the student can only partly achieve the educational goals set at each phase. The student reaches until the data analysis phase.

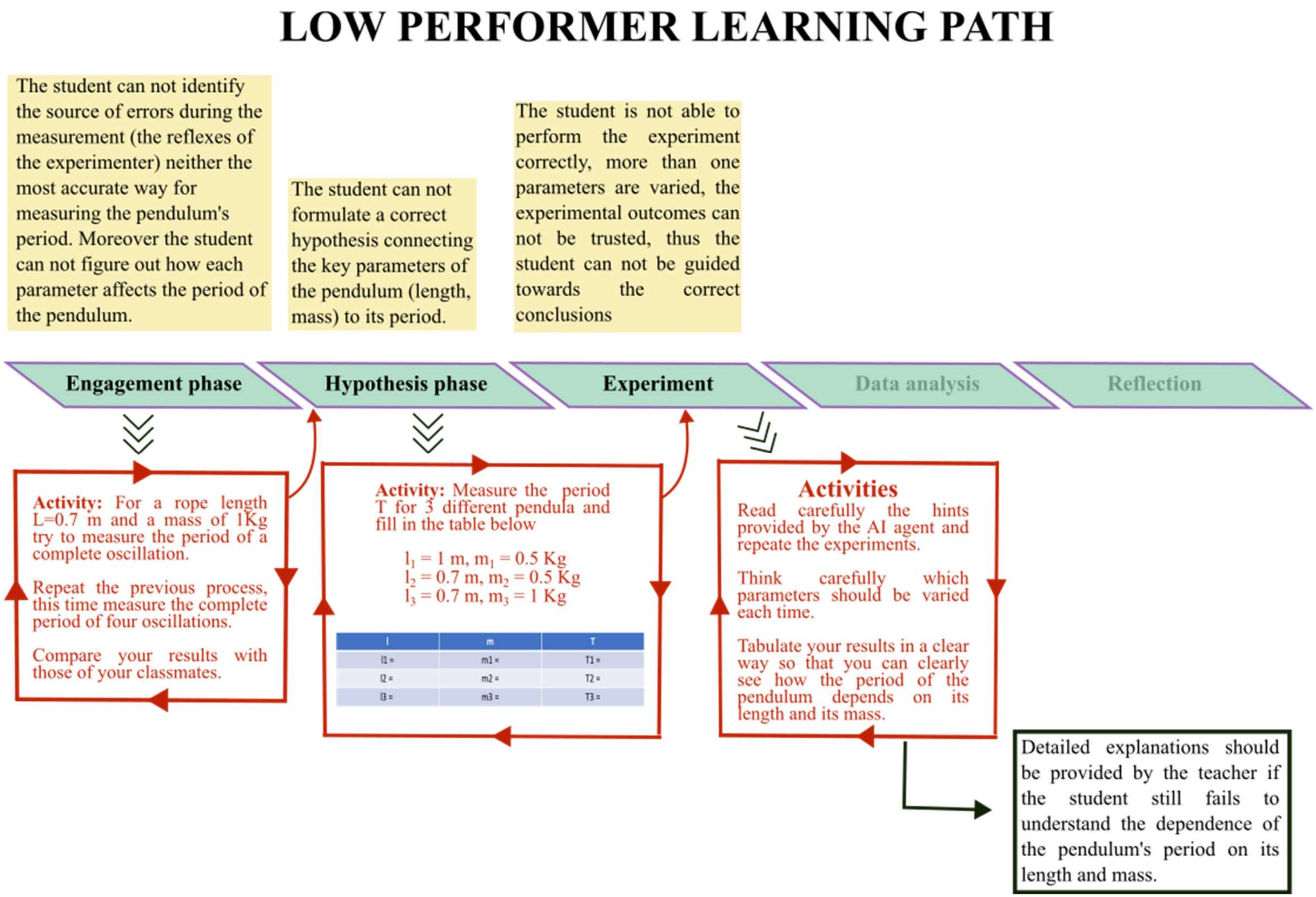


Figure 14: An indicative learning path for an overall low performing student. The student is entering the red loops, where additional tasks are given to him/her by the AI learning companion, to help him/her accomplish the learning goals of each specific phase before moving forward. The student will not have the time to go through all the phases.

5. AI Expected Contribution

Discovery Space will design an Exploratory Learning Environment to facilitate students' inquiry and problem-solving while they are working with virtual and remote labs. It will offer the opportunity to perform personalized scientific experiments with online labs and to develop pedagogically structured and scaffolded learning paths with the support of an AI learning companion and AR and VR interfaces. In such environment students are expected to develop key skills like creative problem-solving competence, critical thinking, collaborative spirit and academic mindset while they will get familiarized with a culture of sharing.

Such an environment is expected to have a central role towards the vision of the creation of the Deeper Learning Classroom which facilitates the transformation of the traditional science classroom to a living laboratory that simulates the research work and introduces students to the scientific exploration. In the framework of the project, the objective of the assessment is to ensure a continued learning process based on the deeper learning paradigm (see Section 2.4) that addresses not just intellectual abilities but also motivational abilities. The deeper learning paradigm incorporates the idea that a range of abilities and their orchestrated skillful application leads to STEM mastery. Considering our approach to develop STEM mastery, that is, students' inquiry experiences during the lab work which include a multitude of options to broadly improve deeper learning abilities, we emphasize its strong innovative character that leads to a challenging assessment process. An evaluation that only concentrates on intellectual abilities and STEM specific knowledge that can also be acquired differently would be far too short sighted to assess all the abilities involved in deeper learning. The interaction of the students with the AI learning companion will allow for assessing the problem-solving competence that is central to deeper learning. The assessment educational data (performance indicators) generated by these interactions can be utilized for creating students' *Deeper Learning competence profiles*. The emerging research field of Learning Analytics can provide a promising approach to introduce such a profiling process for students' Deeper Learning competences, which could, in turn, feed visualization dashboards to facilitate the teacher to have an overview of the students' competence level and development. This kind of overview can facilitate teachers' evidence-based coaching, teaching planning and/or classroom delivery. For this purpose, we will concentrate the students' assessment on the educational outcome that the proposed pedagogical method, which fosters the core abilities involved in deeper learning – proposes to achieve.

The role of AI in the Discovery Space Exploratory Learning Environment will be to minimize the cognitive overload by providing automated guidance and feedback, based on knowledge tracing and machine learning. This feedback will address students' misconceptions and will propose alternative approaches, to support their conceptual change while they explore, and they are performing experiments. The learning companion will guide students to select the most appropriate learning objects based on their profile, skills and competences, digital literacy, possible learning difficulties, and so on. Guidance will be made possible using either companion's conventional Web interface or using an intelligent chatbot with both text-based and voice-enabled interaction (see the indicative scenario in Section 4). The companion's inferencing capabilities will guide the interaction with the students and will learn from it using Reinforcement Learning Methods (see D3.1). Using reinforcement learning, the companion will be able to perceive and interpret the Deeper Learning classroom environment (based on the Deeper Learning Competence Framework), provide guidance recommendations, and learn through students' feedback. In this way, the companion's intelligence will improve upon usage and will provide increased value to students the more it is being used. The companion's capabilities will not only concern the use of learning content but also the engagement of students that will be estimated during the pilots through a series of methods.

Among the most promising is the estimation of the *students' time spent on each task* during the realization of the experiment.

This approach will be tested during the project implementation with numerous students in the participating countries. Considering the well-defined contribution of the different partial abilities to the problem-solving competence as it is presented in formula (1) in Section 3 one can move further by defining the time-dependence of the weighting factors of the problem-solving partial abilities. In fact, this takes us to a more realistic setting as the real classroom environment differs from the PISA controlled test environments from where the reference data are coming from. In the real classroom environment, the duration of each phase is very crucial parameter as possible deviations could affect the realization of the rest, considering that the overall lesson duration is fixed.

If such constraints are to be considered, then the weighting factors of each partial ability should not be fixed anymore but will become time dependent. To include the *time on task*, formula (1) should be written as:

$$f_{PSC} = c_{Eng.}\left(t_{Eng}\right) \times f_{Eng.} + c_H\left(t_H\right) \times f_H + c_{Exp.}\left(t_{Exp.}\right) \times f_{Exp.} + c_{DA}\left(t_{DA}\right) \times f_{DA} + c_R\left(t_R\right) \times f_R \qquad (2)$$

Thus, the time it took the student to complete the scenario, along with the time that the student spent at each scenario phase could serve as reference data for a future re-optimization of our initial assessment model, which was presented in Section 3. To define the $c(t)$ function, the author of the scenario could provide an optimal time that the student will spend at each phase. If the student spends more or less time in this phase, then this should directly influence the value of the function.

Using the system, the students Deeper Learning Profiles will be populated, and the algorithm will provide more accurate and representative values of the weighting factors in equations (1) and (2) facilitating the optimization of students learning paths and possibly providing scaffolds for achieving proficiency in PSC. This is the main impact expected from the implementation of the Discovery Space scenarios in real settings.

Moving forward, a non-trivial goal which could be set by the project's consortium is to further optimize the model to include as input parameters, beyond the time on task, other student data such as the student's performance (during a specific time). For example, the average of a student's grades in Physics, Chemistry, Mathematics and Biology could become reference parameters. These data are expected to populate a student's Deeper Learning Profile, and a meticulous analysis can be performed on the data by the AI learning companion, which in turn should reveal learning patterns to help the teacher understand how each student should be treated, thus achieving personalized learning. Following this path, a more complicated model can eventually be constructed, where the other competencies from which the Deeper Learning Competence Framework consists of will also be considered. In this case the f_{PSC} function will be a component of the new model, which should have the general form:

$$F = c_{PSC} \times f_{PSC} + c_{academic\ mindset} \times f_{academic\ mindset} + \cdots,$$

where the coefficients, the arguments, and the components of the function F need to be strictly defined.

6. Conclusions

In this document we gave a detailed description of the Deeper Learning Competence Framework, the approaches and the environments that promote proficiency in Deeper Learning. More specifically, we focused on the development of students' problem-solving competency and presented a model assessing students' problem-solving skills. The model is based on the implementation of the inquiry cycle while the students are involved in experimental and lab work. To define a starting point for the population of students profiles we have used the PISA definition of the problem-solving competence and its partial abilities. Based to that, students can be categorized in three different levels according to their proficiency in solving complex problems. Moreover, the structure of a Discovery Space scenario was discussed and the different phases from which it consists of were explained.

An illustrative example from the field of Physics (simple pendulum) was presented, while a detailed explanation of the goal of each scenario-phase was also given. The overall purpose of a Discovery Space scenario is not only to assess but by providing the necessary scaffolds to further develop students' problem-solving competence. A detailed scenario is presented as an example to provide a practical implementation of the overall process. The role of the AI Learning Companion is discussed and further analyzed as it offers a unique opportunity to represent in the process the realistic setting of the classroom based on the numerous data that will be acquired during the project's implementation.

This document is expected to become a reference point for the work that will be performed within WP3 and WP4. In what concerns the former, as mentioned above, this document introduced the assessment model and provided all the relative details, thus it should act as a guide for the work that will be performed within WP3. Even more importantly, the presentation of the scenario that took place in Section 4, sets the basis for the work that will be performed within WP4. We note here that for the successful outcome of the project, it is crucial to develop several scenarios, covering different fields of STEM, which should follow the structure of the scenario described here. Finally, as noted in the text when the assessment model was introduced, the model will need to be revisited and further optimized. This process will be summarized in the deliverable, D2.3 The Roadmap for the AI-Enhanced classroom for Deeper Learning in STEM, which is a living document under development and aims to provide the reader with a detailed step-by-step guidance through the different phases of the Discovery Space project.

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