Chapter

Discovery Space: A Technology-Enhanced Classroom for Deeper Learning in STEM

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Abstract

Traditional assessments of cognitive skills (in general) and knowledge acquisition (in specific) are in place in most educational systems. Though not in line with innovative and multidisciplinary curricula as proposed by current reforms, they require in-depth understanding and authentic application. This divergence must be addressed if STEM education is to become a fulfilling learning experience and an essential part of the core education paradigm everywhere. An alternative approach for assessment offers Artificial Intelligence (AI) tools designed to continuously monitor the individual progress, provide targeted feedback, and assess the student's mastery. All this information might be collated throughout a student's time in formal (and in some cases in informal or non-formal) educational settings. While the use of AI-driven continuous assessment offers a replacement of high-stakes stop-and-test examinations, its application needs to take into consideration its benefits and challenges. These applications (AI-enabled adaptive and continuous assessment) have been heralded as constituting a "fourth education revolution." However, concerns include challenges regarding their effective integration into educational practice, the lack of robust evidence for their efficacy and potential impact on teachers' roles. In this chapter, we present our vision based on long-lasting experience in employing ICT-based innovations in education. Our roadmap for the AI-enhanced classroom for deeper learning in STEM is supposed to facilitate the transformation of the traditional classroom to an environment to promote scientific exploration and support the development of key skills for all students. We describe the findings from a large-scale foresight research exercise that increases the understanding of the potential, opportunities, barriers, and risks of using emerging technologies (AI-enabled assessment systems combined with AR/VR interfaces) for STEM teaching. Our approach builds upon the extended use of an Exploratory Learning Environment that has been designed to facilitate students' inquiry and problem-solving while they are working with virtual and remote labs. By enabling this platform with AI-driven lifelong learning companions to provide support and guidance we intend to enhance learning experiences, facilitate collaboration, and support problem-solving. The provision of elaborated Good Practice Scenarios may adjust options for learners of quite different achievement levels and equip them with the skills necessary for the use of technology in creative, critical, and inclusive ways.

Keywords: artificial intelligence, deeper learning, AI-enabled learning companion, STEM-education, smart science classroom, alternative assessment methods

1. Introduction

The recent lockdown has thrust us into a period of fast-moving digital reforms in education, which requires us to respond accordingly. We need to empower teachers to make the most of digital advances and provide various digital learning solutions while we learn to understand how technology can foster deeper learning. This entails reconsidering student learning, how technology can support it, and how to combine their expertise as a profession. In turning the promises of education technology into reality, students were one of the most vulnerable groups to the coronavirus school lockdown times imposed by policy authorities. The crisis had relentlessly disclosed inadequacies and inequities in our education systems – not only the lack of broadband and computers needed for online education but also additional support for learning environments enabling a focus on learning. While the crisis had amplified inequities, it also offered opportunities to not return to the status quo when things return to "normal." When authorities closed down schools in early 2020 to deal with the COVID-19 pandemic, learning suddenly had to go online. For teachers, students, and administrators, this change initiated a collective pile-up of courses on digital education – often without any previous planning [1]. All of us know about the avalanche of downsides, starting from screen fatigue and adaptation stress until the individual failure to deal with digital learning or the students' unpreparedness to learn on their own. However, the unexpected experience urged education systems for rapid changes, without chance of slowcoaches to gradually prepare for innovation and steward for smart schooling [2].

Within the described circumstances, remote classrooms were not smart ones. This was especially true, as it had to act as a stop-gap measure to keep learning going and conserve existing educational practices rather than act as a transformation agent. In consequence., remote classrooms rarely were able to substitute physical ones. Although major syllabus deficits apparently were avoided, online classes could bridge neither technologically nor mentally the sudden gap. An example are science classrooms and labs [3]. In most EU countries, experimental hands-on work, inquiry-based activities, and problem-solving tasks have not found their digital twins during the schools' closure. Even in hybrid schemes of delivery of education services, the restrictions posed created a rather problematic framework for the implementation of inquiry-based projects and activities. At the same time, the introduction of inquiry-based approaches into school curricula remains a major priority in Europe [4]. Most authors regard inquiry as the appropriate catalyst to clear the ground for students' deeper learning competence (academic knowledge, problem-solving skills, cooperation and creativity, and/or development of academic mindset) [5]. It has great potential for supporting the academic success of students, bridging gender gaps, and producing a well-qualified workforce with optimally adopted Science Technology Engineering, and Mathematics (STEM) skills [6, 7]. Research in science education provides clear evidence that learning in an active way is regarded as a necessary condition for acquiring deep knowledge and skills [5, 8–10]. Inquiry learning (often based on hands-on experiments) may easily allow students to make active choices (choosing the next step in performing an action, for instance by changing a variable), experience the consequences of their own actions, and adapt individual knowledge and skills in response to an experimental set. Beyond remote learning, the assessment of the development of those competencies consists of a major challenge for educational systems [7, 4].

There is a major mismatch between opportunity and action in most education systems today. One of the most consequential mistakes of classroom education originates in the divorce of the learning process from assessment; that is, having students pile up lots of learning and then, testing whether they could reproduce some narrow slices of that learning within a short time slot. Although the validity, reliability, or accuracy of high-stakes examinations are heavily disputed, almost all educational systems around the world are building upon them. This basic trust on examinations in place imposes schools and universities often teach just for the test, prioritizing routine cognitive skills and knowledge acquisition by neglecting in-depth understanding, and authentic application. These approaches, however, are not harmonized with the innovative and multidisciplinary curricula proposed by current reforms focusing on the development of twenty first-century skills, mainly in STEM education [11, 12]. Educational systems are still adopting traditional assessment methodologies that cannot monitor the development of students' competencies while working on specific tasks and experiments, making hypotheses, creating models, solving complex problems, reflecting on everyday phenomena and situations, and learning how to think scientifically [13]. This divergence must be addressed if STEM education is to become a fulfilling learning experience and an essential part of the core education paradigm everywhere [14, 15].

What can technology do for smart classrooms? First of all, a reintegration of learning and assessment would help as well as options to use real-time data and provide feedback to help students learn better, but also teachers teach better and more effectively [16]. While kids are studying science on a computer, the AI system can shadow how we study and in this way make our learning experience more adaptive and interactive. In line with sensors and appropriate management systems, AI can feed back how students learn differently, in which topics they are interested or distracted, and where and when they advance or get stuck [17, 18]. Technology can help to adapt learning to various student needs and give learners greater ownership over what they learn, how they learn, where they learn, and when they learn. AI has already invaded educational contexts in multiple ways by using cutting-edge technologies: Nevertheless, those applications often do not have more than the programmed lessons of the 1970ies which automate some outmoded classroom practices. AI can offer more sophisticated channels by using unique affordances to reimagine teaching drastically. In other words, the attention of AI developers so far has focused on the relatively easy-to-address tasks such as memorizing and recalling knowledge [19]. Address more complex educational issues, such as collaborative learning options or new ways to assess and accredit, would offer quite other paths.

An alternative approach to assess twenty first-century competencies might originate in AI tools designed to constantly monitor student progress, provide targeted feedback, and assess student's mastery [20]. All this information throughout a student's time in formal (and in some cases in informal or non-formal) educational settings might contribute to the consistent support of an individually formatted framing [17, 21]. While AI-driven tools replace high-stakes test examinations, it signals and illustrates the two sides of applying AI in education: the benefits and the challenges. Allowing students to demonstrate their competencies while they learn is advantageous. These applications (AI-enabled adaptive and continuous assessment) have been heralded as constituting a "fourth education revolution" [22, 23]. However, it is important to acknowledge at the outset that the use of AI for learning and assessment also raises various concerns that are yet to be properly addressed. These include challenges regarding their effective integration into educational practice, the lack of robust evidence for their efficacy and potential impact on teachers' roles, and broader ethical questions.

An AI-enhanced classroom for deeper learning in STEM needs research in the field and long-lasting experience in the implementation of ICT-based innovations within educational settings [17]. In proposing a tangible approach to respond to those challenges, a consistent roadmap for the AI-enhanced classroom for deeper learning in STEM is required to facilitate the transformation of a traditional classroom into an innovative environment and allow the latter to promote the scientific exploration of subsequent development of key skills for all students [24]. In the following sections, we are presenting an AI-enhanced environment, enhanced with scaffolds and visualizations that have been designed to introduce students to scientific exploration and inquiry, while, at the same time, supporting the development of their problem-solving competence [25, 26]. We are also presenting a number of good practices that have been designed to guide the integration of the proposed environment into school practice.

2. The discovery space exploratory learning environment

2.1 Technical description

The use of the Discovery Space Exploratory Learning Environment intends to achieve simplicity at all levels to overcome the existing barriers that are currently limiting online and remote lab applications in educational practice, sharing, and exploitation outside early adopter communities. Its use focuses on simplicity for students to conduct inquiry-based learning activities with online labs in a user-friendly environment that includes scaffolds and guidance during the experimentation, for teachers to repurpose and exploit these resources without third-party interventions, for teacher communities to share practices and scaffolding solutions, and for the lab providers to offer their resources online. The system is a single-entry point for all stakeholders integrating individual labs or repositories, learning activity spaces, associated resources, and supporting communities. There is no need for teachers and students to invest in deploying or integrating the technology at their place. Following the Web 2.0 paradigm, the environment is ubiquitously accessible to everybody from everywhere at any time and continuously updated to fulfill the needs and expectations of science education individuals and communities. It consists of three main components, The Discovery Space Management System, the AI-driven Lifelong Learning Companion, and the AR/VR Interfaces:

The first, the Discovery Space Management System, is the software architecture in charge of containing and offering the different functionalities, services, and tools integrated with the Discovery Space Exploratory Learning Environment. The second, the Discovery Space AI-driven Lifelong Learning Companion, is a tutoring tool. Rather than setting out to teach the student in the manner of an instructional Intelligent Tutoring System [25], it may act as a learning companion providing continuous support, following the students' learning paths, and even helping them to decide what to learn. By offering individualized learning pathways designed to help to address their learning interests and take their achievement levels into account, while encouraging to reflect on and revise long-term learning aims. Guidance is made possible using either a companion's conventional Web interface or an intelligent chatbot with both text-based and voice-enabled interaction. The latter, the Mixed Reality Interface [27], could also offer augmentations of graphs, videos, or animations related to the phenomenon under study. Such applications have proven their efficiency to also engage low-performing students in the experimental process. Some MR innovations use AI techniques to control lifelike virtual avatars, enable voice control using natural language processing, or generate entire environments from a few starting images. When reconsidering MR in a learning context today, the general miniaturization and high integration of computers, and recent trends in digital-supported schooling (not least due to the pandemic) provide several routes for integration and evolution. The first one is a "mobile-first" implementation for devices like smart-tables and smartphones that are widely deployed (and increasingly so in school contexts). The second route is to employ microcontrollers and single-board computers like Arduino, BBC micro:bit, or Raspberry Pi. All of them are widely deployed in education as well and might be able to run a compelling AR experience on otherwise very versatile platforms that come ready-at-hand with standard IO-channels and visual-programming environments such as Scratch that support reaching technological inspiration and learning problem-solving skills. The third route is to concentrate on "web-first," browser-based integration which supports the ease of deployment for teachers and students.

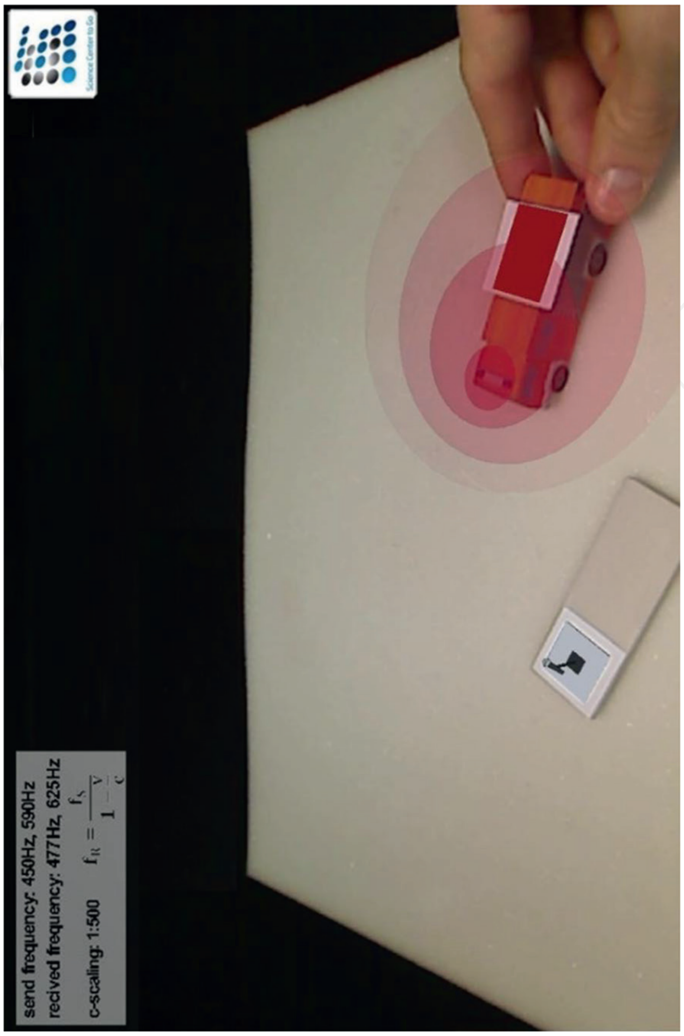
2.2 Benefits for the users

While using the system, students are encouraged to actively construct their own knowledge by exploring the learning environment and making connections with their existing knowledge schema [e.g., [28–30]]. An AI Learning Companion needs to assign a role to minimize the individual cognitive overload that is often associated with exploratory learning. Providing automated guidance and feedback, based on knowledge tracing and machine learning might offer a way to solve this issue [31, 32]. Even misconceptions can be addressed individually in supporting a student while performing his/her experimental task [33, 34]. The AI-driven lifelong learning companion will support students in developing their learning paths that will provide structure to the student experience and thus allow every single person to pursue goals that require extended engagement or persistence across multiple contexts and learning opportunities (see **Figure 1**).

The role of teachers in such an exploratory learning setting is that of a "facilitator," or "orchestrator" of learning processes [35–37]. 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 tasks that students are working on, is 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 own inquiry into more conceptual student learning.

While using the system, students actively need to construct their knowledge by making connections with their existing knowledge schema. AI might help to minimize the cognitive overload that is often associated with exploratory learning by providing automated guidance, based on the individual learning progress. This individualized feedback includes misconceptions and proposes alternative approaches while students are performing an experimental task. 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 every single person to pursue goals that require extended engagement or persistence across multiple contexts and learning opportunities.

The Discovery Space Exploratory Learning Environment is designed to facilitate and support implementation scenarios of different levels of complexity. In the next section, we are presenting three such scenarios: In the first, we describe the potential that the use of such a system holds for the upgrade of everyday teaching. In the second, we explore a more demanding implementation where visualizations and animations are activated to facilitate student's understanding of complex and invisible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recived frequency: 477Hz, 625Hz
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Figure 1.
Students have significant difficulties to understand the wave concepts and their propagation [38]. An exploratory learning environment enabled with scaffolding and visualizations could facilitate a deeper understanding of these phenomena. For example, the Doppler effect experiment [27] allows moving a sound source relative to a listener. The sound source could be a fire truck or an ambulance while a virtual microphone transfers the sound. As in real life, the microphone input results in a change of pitch when either of the objects is moved. This miniaturized setup allows a simulation with small movements presenting a remarkable effect due to the reduced scale. Additionally, visualizing the sound wave further improves the understanding of wave propagation of relatively moving objects. Guidance (in the form of text, formulas, graphs, or animations) is augmented to the optical view of the student during the experimentation.

concepts and phenomena. The final scenario refers to a quite demanding implementation where the students have the chance to use a combination of remote and virtual laboratories to get a full experience of the scientific inquiry.

3. Good practice scenarios

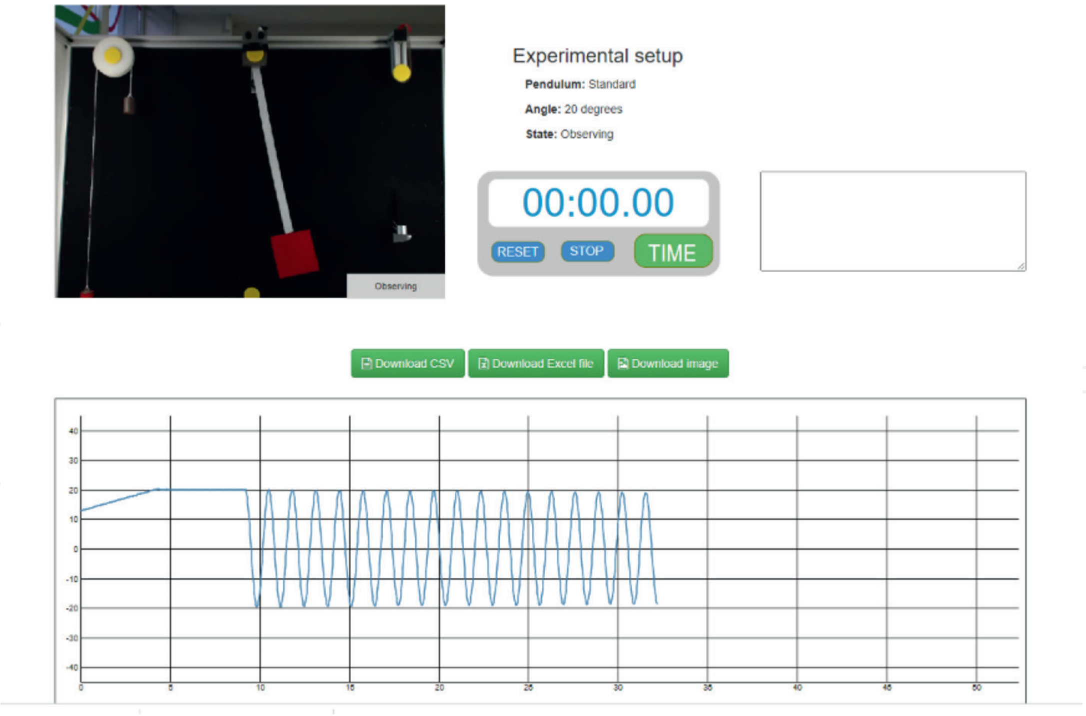
3.1 Enhancing the school-lab-work: simple harmonic oscillation

In this scenario, we are focusing on the simple harmonic oscillation concepts, mostly the concepts about restoring force, characteristics of simple harmonic oscillation, velocity, acceleration, period, and energy. The concept of simple harmonic oscillation is very important in physics because it is essential for considering phenomena of mechanical oscillation, sound, and light, as well as quantum theory. In fact, students run into a variety of problems with inconsiderate harmonic oscillation [e.g., [35]]. Most students experience misconceptions related to the frequency of the simple harmonic motion, the relationship of the rope length to the pendulum period, and the dependence of the frequency with the oscillating mass [36].

In the specific scenario, simple harmonic oscillation concepts have been reached through experimentation with a simple pendulum. A remote lab is used as it offers the opportunity for each student to perform the experiment following his/her own learning path and inquiry strategy. By using the AI Learning Companion to interact with the students during the experimentation with the pendulum, it is expected that students show a sound understanding of simple harmonic oscillation and relate to the concepts. The AI Learning Companion can activate augmentations, virtual simulations, or related graphs that can help students in their conceptual understanding (**Figure 2**).

3.2 Visualizing the invisible: why do planes Fly?

This scenario expands the limits of the school classroom. Students in the framework of a field trip have the chance to explore the forces acting on an airplane wing and their effects on it [39, 40]. Airplane wings are designed so that the airspeed above the wing is greater than that below the wing. As wings have slight upward



Experimental setup

Pendulum: Standard

Angle: 20 degrees

State: Observing

00:00.00

Figure 2.
The discovery space exploratory learning environment provides access to numerous remote and virtual labs to facilitate students' introduction to scientific methodology. The figure presents a remote pendulum for the study of the parameters of simple harmonic oscillation. The remote experiment is enriched with numerous augmentations that are activated on different occasions as the students experiment with the device, according to the student's level and proficiency in performing the foreseen tasks. Additional support through the activation of virtual experimentations is also provided.

tilts, air molecules strike their bottom to be deflected downwards. In consequence, wings are exerting a downward force on the air as according to Newton's third law an opposite force develops lifting the wing. Nevertheless, if wings are tilted too much, the airflow across the upper surface due to turbulences diminishes the pressure difference across the wing. The high relevance of this phenomenon to the curriculum affects numerous concepts: Forces and motion (Newton's first and third law, quantitative relationship between force area and pressure, air resistance, and drag) air pressure, and/or density. The Airplane Wing is an interactive exhibit (see **Figure 3**) using a simple fan that is operated with an illuminated push button and blows air across an experimental wing. The fan goes on for approximately 30 seconds and blows air across the wing. The wing pivots on a horizontal tube that can be tilted by the operator at a steep or narrow angle to the airflow that is blowing across it. Table tennis balls are encased in the wing, which is made of clear Perspex. The independent variable manipulated by the user is the wing and the dependent variable is the lift generated at each angle of the wing, represented by the position of the ping-pong balls. The students' interactions are based on focal research questions: How do airplanes fly? What factors influence lift? How does lift depend on these? Why do the ping-pong balls in the exhibit move up and down?

A common students' misconception is that lift is created due to Bernoulli's effect providing problems regarding the invisible nature of the phenomenon [40]. Students often (i) neglect the effect of air movement on an airplane's lift, (ii) are unaware of the presence of air pressure, especially when air is not moving, or (iii) do not analyze the lift of an airplane's wing in terms of forces. Theories of flight however are not in the curriculum at this stage, so most students probably have not thought about flight.

The AI Learning Companion will be present during the students' interaction with the exhibit providing guidance and support in students' understanding and conceptual change. As students have the chance to interact with the exhibit in different ways, the AI Learning Companion can facilitate the development of learning paths based on

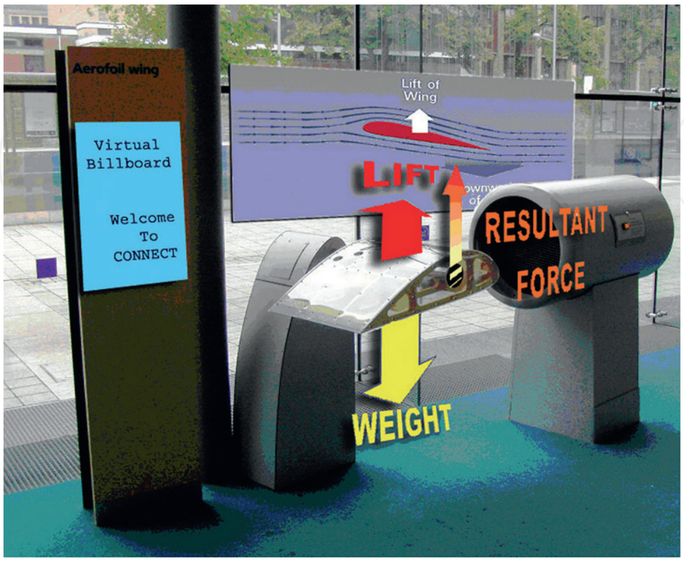


Figure 3.
The discovery space exploratory learning environment provides opportunities to expand classroom-based activities. In this scenario, the airplane wing is enriched with augmentations and visualizations that are activated while students are interacting with the wing. The augmentations offer opportunities for personalization as the students can follow their own learning path while interacting with the exhibit.

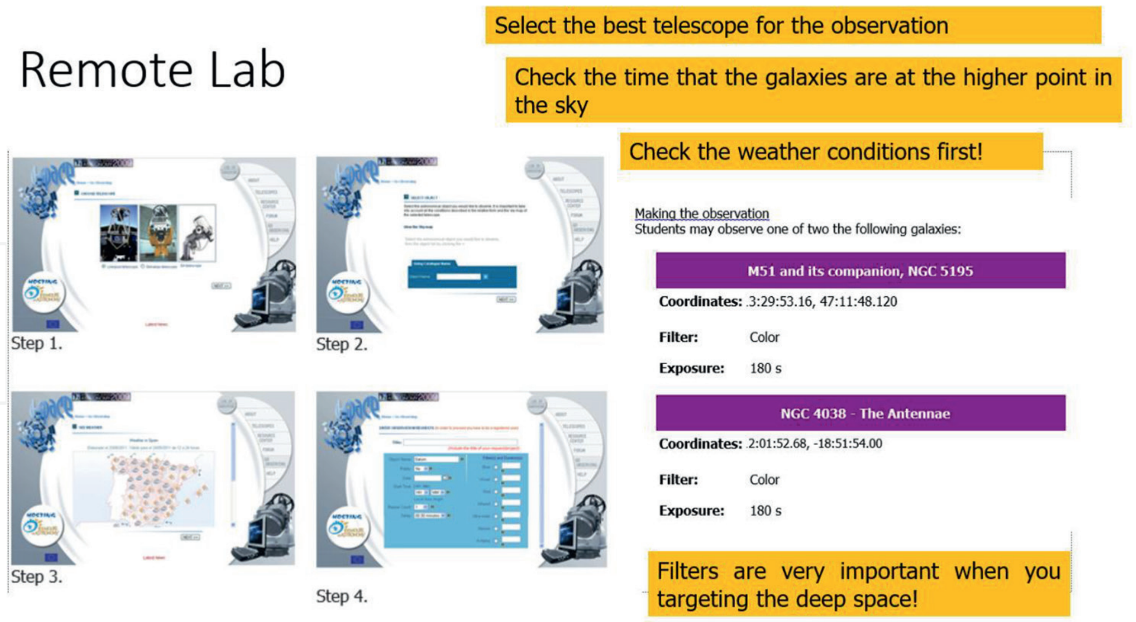
the previous experiences of the students and their understanding of the problem. In this case, the dialog between the student and the system can be enriched with images, animations, or even more advanced augmentations that could be realized according to the level of problem-solving competence of the students.

3.3 Real-life scientific inquiry: studying the collision of galaxies

The Discovery Space Exploratory Learning Environment could provide support for the involvement of students in quite complex tasks by providing personalized guidance and support. The case of remote telescopes in educational contexts is such an example. Although far distant from classrooms, a robotic telescope can made available for undergraduates in real-life research contexts by offering an authentic experience. It can encourage curiosity just at that point of an education career where the content itself can start to become quite dry and overloaded. For continuing astronomy careers throughout undergraduate times, access to robotic telescopes might maintain curiosity and discovery appetite by making observational data available that may be taken at face value otherwise. Those students who may be continuing toward higher level courses or even deciding on a scientific career may want to dig a little deeper into astronomical research during their undergraduate experience.

By having remote or robotic telescopes accurately and automatically aligned, all the stress of setting up the telescope and pointing, which requires a lot of skill and practice, is removed from the teacher or the student. Telescopes are located at distant spots, allowing access from all over the world and requiring just a small group of professionals for maintenance [41, 42]. A variety of benefits to the telescope user are apparent: Compared to mobile telescopes more effective mounts and larger apertures are possible. Physically damage of telescopes is next to impossible, no time expenditure to set up, pack up, or maintain the instrument by users do not apply. The technical knowledge necessary for use can be minimized through a well-designed user interface.

The Discovery Space Exploratory Learning Environment provides as a user interface constant support beginning with technical knowledge substituting high initial investment cost [43]. And not to forget, there is access to either the Northern or Southern hemisphere, exceeding the one where students are physically located, opening more objects in the night sky to view. The access procedure typically involves a request within an online automated scheduler which in return provides an image (autonomous control), or through direct remote control of a telescope, located in a favorable time zone (remote control). **Figure 3** presents the interface of the Discovery Space Exploratory Learning Environment. Students must select the telescope (taking into consideration the observation target and the location of the selected telescope), set the observation parameters, and check the weather conditions in the location. The AI Learning Companion will interact with the student at different stages and will support the students' inquiry and understanding of the process [44]. A series of possible interactions are presented in **Figure 4**. These interactions will be activated by the system only if the students face difficulties in accomplishing the task and help to provide a different interpretation of the "scientific method" involving observation, simulation, and theory, rather than the typical pre-arranged experimental textbook approach commonly provided. This way of authenticity may improve an otherwise uninspiring school experience. Robotic telescopes also support strong links with pure physics, by utilizing concepts to do with light, gravity, and instrumentation. Looking at objects' sizes and ages in the Universe may offer a less abstract/theoretical basis



Remote Lab

Select the best telescope for the observation

Check the time that the galaxies are at the higher point in the sky

Check the weather conditions first!

Step 1.

Step 2.

Step 3.

Step 4.

Making the observation
Students may observe one of two the following galaxies:

M51 and its companion, NGC 5195

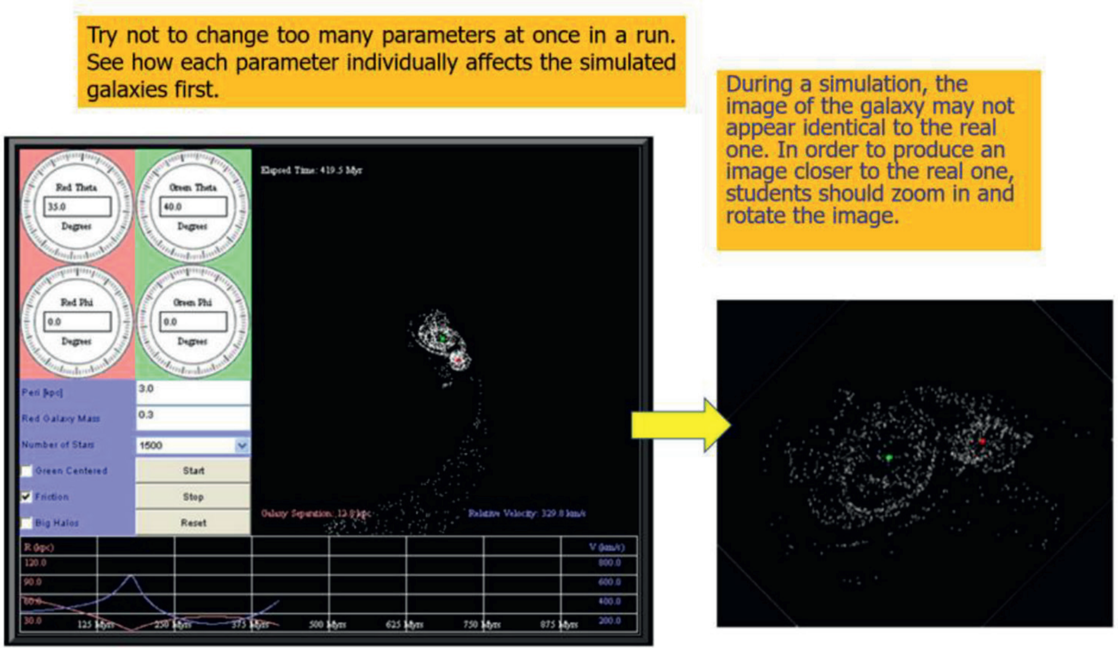
Coordinates: 3:29:53.16, 47:11:48.120
Filter: Color
Exposure: 180 s

NGC 4038 - The Antennae

Coordinates: 2:01:52.68, -18:51:54.00
Filter: Color
Exposure: 180 s

Filters are very important when you targeting the deep space!

Figure 4.
While students are using the discovery space interface, the AI learning companion is present to support their inquiry. In the specific case, the possible interactions with the AI learning companion are indicated in the orange boxes. These interactions are activated according to the student's proficiency to handle the remote telescope interface. They are presented in a progressive way to support students' understanding of the process and to introduce them to the scientific inquiry.



Try not to change too many parameters at once in a run. See how each parameter individually affects the simulated galaxies first.

During a simulation, the image of the galaxy may not appear identical to the real one. In order to produce an image closer to the real one, students should zoom in and rotate the image.

Red Theta 35.0 Degrees
Green Theta 40.0 Degrees
Red Phi 0.0 Degrees
Green Phi 0.0 Degrees
Peri [kpc] 3.0
Red Galaxy Mass 0.3
Number of Stars 1500
☐ Green Centered
☑ Friction
☐ Big Halos

Elapsed Time: 419.5 Myr

Galaxy Separation: 12.0 kpc

Relative Velocity: 329.8 km/s

Figure 5.
Students with higher levels of proficiency or great interest in the experiment have the chance to explore more advanced interventions. In this specific case, students are studying the collision of two galaxies in simulation software. The aim is to create a model that is quite close to the image they received from the remote telescope. In such a complex activity, numerous parameters must be considered. Those activities help students to demonstrate critical thinking and high levels of scientific proficiency. It is not possible to create such conditions in traditional learning environments where the teacher supports many students with different proficiency and knowledge levels at the same time.

for studying time, distance, and size scales. The general understanding of astronomy by high-school or undergraduate students is generally low, at any level, they typically also have very little knowledge of the night sky in terms of constellations and major stars, and limited practical knowledge beyond the reach of the naked eyes. The Discovery Space Exploratory Learning Environment provides additional opportunities for students who demonstrate higher levels of proficiency during the intervention [44]. For example, in **Figure 5**, we are presenting a rather complex activity where a simulation tool for modeling the crash of galaxies is used. The task that has been assigned to students who have demonstrated high levels of science proficiency and problem-solving competence is to reproduce the images they have got from the remote telescope through this simulation software. In such a way, the AI Learning Companion could optimize the instruction to meet the needs of all students, including low and high performers at the same time [45]. Such interventions are not possible in traditional classroom environments.

4. Conclusions and future developments

There is a wealth of learning science literature about supporting inquiry-based learning in Exploratory Learning Environments [46, 47] and, more specifically, in virtual labs [4]. There are several advantages of such environments: (i) By aligning with a scientific inquiry cycle students might more easily encounter a cognitive conflict between existing ideas and data that comes from experiments. Such conflicts very likely would stimulate students' adaptation to existing knowledge. This theoretical notion is closely related to cognitive theories of schema development and adaptation. (ii) Within the impetus for science learning online labs and accompanying simulations often use multiple representations [4]. 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 [48]. 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, 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 [4]. A fourth relevant theoretical approach is constructionism [47]. 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 [25]. In these cases, instructional support is needed for successful learning [7]. 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 also involves many ethical concerns [47].

The role of AI in the Discovery Space Exploratory Learning Environment is to minimize cognitive overload by providing automated guidance and feedback, based on knowledge tracing and machine learning. This feedback addresses students' misconceptions and proposes alternative approaches as well as supports their conceptual change while they explore and perform experiments. The technological innovations in Discovery Space aim at simplicity at all levels to overcome the existing barriers that are currently limiting online and remote lab deployment in educational practice, sharing, and exploitation outside early adopter communities [49]. Discovery Space focuses on simplicity for the lab providers to offer their resources online [50], for the teachers to repurpose and exploit these resources without third-party interventions, for teacher communities to share practices and scaffolding solutions, and for the students to conduct inquiry-based learning activities with online labs in a user-friendly environment that includes scaffolds and guidance during the experimentation.

Acknowledgements

We appreciate the support of the Discovery Space project's partners as well as all involved schools and teachers.

Funding

This research was funded by the European Erasmus-Plus Program (Discovery Space: grant ERASMUS-EDU-2022-PI-FORWARD, Project: 101086701) as well as by the Ellinogermaniki Agogi (EA) and the University of Bayreuth (UBT). Additionally, we received funding from the Open Access Publishing Fund of the University of Bayreuth (German Research Foundation, grant number LA 2159/8-6).

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