ENhance VIrtual learning Spaces using Applied Gaming in Education

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D1.3

Educational scenarios and stakeholder analysis (Update)

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Abstract

This document consists an updated part of Deliverable D1.1 that presented the initial requirements from a group of stakeholders (teachers, teacher trainers and school advisors) and provided a definition of the types of educational scenarios that the ENVISAGE authoring tool should support. Based on the proposed framework the project team has selected a series of virtual labs and performed an analysis of the reactions of the stakeholders during a series of real-life pilots. In total eleven pilots were conducted for the first iteration of the ENVISAGE services. Two for each of the authoring and visualizations tools and seven for the virtual labs (including six pilot implementations in school environments with students). According to the findings of D5.2 stakeholders saw a great potential in using the system and

they are hence potential users of the finished product. Improving the UI further would therefore help accommodating the user's requests and hopefully, attract them as end-users. Encountering difficulties in the early version of an IT-system is to be expected, however the participants still expressed enjoyment about the possibility of being able to create a 3D experience for their classroom. Overall, the users evaluated the labs with positive feedback. They liked the content and believed the proposed labs should give the students a deeper understanding of the subject. The also clearly saw the learning goals of the labs. Based on the stakeholders' feedback we are presenting a series of updated educational scenarios that will serve as prototype demonstrators for the second pilot phase of the project, emphasising the added value of the ENVISAGE concept to the design of more engaging activities that promote the development of proficiency in problem solving competence. These scenarios are presenting three different cases that according to our view will offer the opportunity to the project team to highlight the potential of the ENVISAGE concept a) the enrichment of an existing widely used virtual lab with deep analytics, b) the integration of three existing labs in a common environment, and c) the extension of an existing lab that was used during the first pilot phase to more complex real-life environment where numerous activities can take place. These scenarios (along with the requirements to be presented in D1.4) will feed into WP5 for specifying the virtual labs to be designed and developed using the authoring environment (WP4) and will provide the test bed for evaluating the effectiveness of the developed technologies in WP2-4 to address the stakeholder requirements.

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Executive Summary

The current document aims to present three additional scenarios of use for the ENVISAGE system based on the feedback received from the users (mainly teachers) during the first pilot implementation. The requirements elicitation process was based on the interaction with teachers and students. The document also emphasizes on the use of deep analytics and their potential value in the ENVISAGE service. The ENVISAGE virtual labs, integrated to full educational activities and lessons could provide useful data (through the combination of shallow and deep analytics) for the assessment of the problem-solving competence of the students involved in the task. This document has to be considered as an additional part of D1.1 based on the findings of the first year of the implementation of the ENVISAGE project. It includes 6 sections:

Section 1 presents the ENVISAGE concept and acts as the connecting framework with the work done in WP1 and in the other WPs of the project.

Section 2 emphasizes the potential of the ENVISAGE education approach on creating opportunities for deeper learning in science. The chapter describes the main characteristics of teaching for deeper learning and highlights the areas where ENVISAGE could demonstrate significant added value. Sections 3, 4 and 5 present three specific cases on how the ENVISAGE approach could optimize the design and implementation of virtual labs and could enhance the learning process in a virtual lab by offering personalized learning content.

Section 3 presents the enrichment of an existing widely used virtual lab with deep analytics. Following the extended presentation of shallow and deep analytics in D1.1 in this document we are presenting a scenario that demonstrates how parameters like the time on task (shallow analytics) could be combined with deeper analytics (students' proficiency level based on the complexity of the task) to provide insights to students learning process and on how it can be supported by the ENVISAGE system. In this framework we are using the case of the HYPATIA virtual lab (see Section 6.9, D1.1) that introduces students to the key concepts of High Energy Physics and Data Analysis.

Section 4 presents the integration of three existing labs in a common environment. The ENVISAGE environment and its authoring tool offers the opportunity to teachers to present more interesting and realistic lab conditions to their students. The ENVISAGE environment could act as an integrated environment that combines different labs. In this framework we are offering three virtual labs that involve low and medium level problem solving tasks, the Building Atomic Orbitals (see Section 6.2, D1.1), the Building Inorganic Molecules (see Section 6.3, D1.1) and the Organic Molecule Builder (see Section 6.6, D1.1) in a common lab-like environment to offer an integrated experience to students.

Section 5 presents the extension of an existing lab (see Section 6.5, D1.1) that was used during the first pilot phase to more complex real-life environment where numerous activities can take place. It includes hands-on, critical thinking activities that help secondary students to develop a comprehensive understanding of the scientific, economic, environmental, technological, and societal aspects of wind energy.

Section 6 presents the main conclusions.

Abbreviations and Acronyms

HYPATIA	Hybrid Pupil's Analysis Tool for Interactions in Atlas
PD	Professional Development
PISA	Programme for International Student Assessment
STEM	Science, Technology, Engineering, and Mathematics

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1 Introduction

1.1 ENVISAGE Concept

The overall concept of ENVISAGE is based on iterating the process of improving virtual labs through a pipeline that i) starts from the current version of a lab, ii) collects shallow analytics extracted from user behavioural data, iii) digs deeper into the obtained analytics using machine learning methods, iv) integrates the obtained information under the authoring tool, v) employs the authoring tool to build an improved version of the virtual lab and finally vi) iterates the above process. The approach of ENVISAGE is illustrated in Figure 1-1. First approach is the monitoring of the activity of the users and the modelling of their current behaviour through the use of shallow analytics (simple statistics on tracked data). Afterwards, the second approach is to predict in a reliable manner the future behaviour of the users through the use of deep analytics (which is outcome of the application of machine learning algorithms). Both of these approaches combined with state-of-the-art visualization methodologies will offer insights on what features are important and what functionalities users expect to find in a virtual lab. These insights will allow for a) optimizing the design and implementation of a virtual lab and b) enhancing the learning process in a virtual lab by offering personalized learning content.

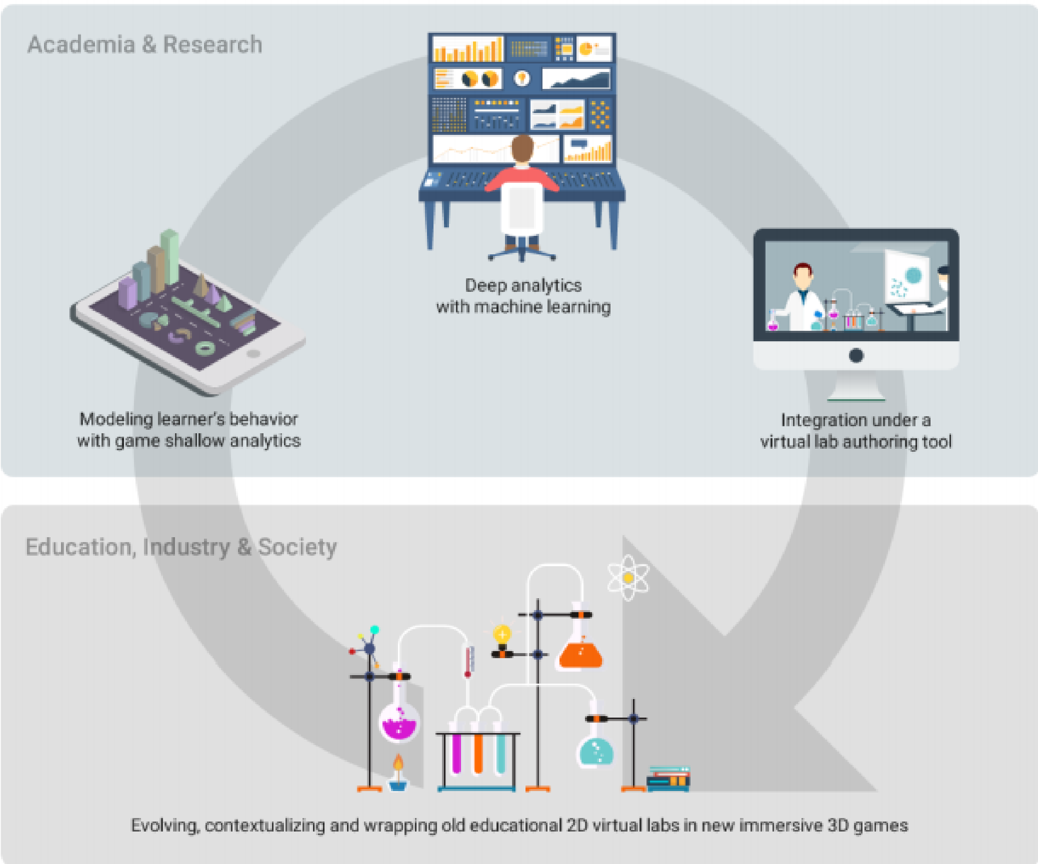

Figure 1-1: The ENVISAGE virtual lab enrichment strategy through a four step approach.

1.2 More efficient and effective learning, through mainstreaming new ways of learning with virtual labs and more efficient ways of assessing learning outcomes

The ENVISAGE service will facilitate the use of virtual labs in schools by promoting and applying the following methods:

● **Inquiry-based learning with virtual labs, which has already proven its effectiveness in school education.** Studies show that students learning with virtual labs gain more knowledge than students following expository instruction and more advanced knowledge than students who learn in a real lab. Provided within a structured learning environment (or even embedded in the experimentation process) and accompanied by inquiry learning apps, virtual labs give students the possibility to go through the whole inquiry process, starting with the formulation of research questions and hypotheses, via investigation and experimentation, ending with analysis of the experiment data, drawing conclusions, and discussing the results,

● **Learning by modelling, which supports students' understanding and reasoning about structures.** Using such applications students will be able to create and investigate models of scientific phenomena, uncovering interrelationships between and within those phenomena. This will contextualize students' learning activities and knowledge and help them draw parallels with and better understand the world.

Furthermore, ENVISAGE will develop a set of analytic modules assessing students' skills development, allowing to combine technical solutions with learning challenges (e.g. identification of misconceptions at an early stage of the experimentation process). These skills include, for example, thinking skills (e.g., problem solving, critical thinking and reflection) and social competencies (e.g., collaboration and communication). These skills will be acquired and applied by the students in the inquiry learning context. Moreover, innovative facilities for monitoring and assessment of the students' progress (using both shallow and deep analytics), will be available: 1) The teacher will be able to monitor students' work, having direct access to the experimentation space and, thus, the possibility to view student's progress and provide assistance, if needed. 2) Summaries of the students' activities and progress in the personalized experimentation spaces will be provided to the teacher at the end of the teaching session allowing monitoring of the work in the classroom and timely reaction in case of any questions or problems. 3) Advanced learning analytics functionalities will be available, allowing monitoring of the learning process and assessment of the learning outcomes. A feedback mechanism will allow to provide feedback on students' performance, related to specific learning activities. 4) Students will be able to view analytics of their own learning process and results and reflect on them and document conclusions using a self-reflection app.

The ENVISAGE innovation building methodology will include evaluation metrics and benchmarking activities, on the design and deployment of innovative Science learning practice and school organization change, by using the proposed virtual labs and resources, while it will be coupled with an evaluation framework, evaluating progress on learning achievements, based on the **PISA 2012 Framework for the assessment of the problem solving competence** of the students and teacher professional development and school organization change, which will accompany and support the running of the pilots. This approach will offer the basis for the validation of the introduction of ENVISAGE tools in

European schools, so that piloting and field testing results can be collated and analyzed systematically and then disseminated widely, thus ensuring real impact and widespread uptake.

1.3 User groups and their perspectives

Virtual Labs Developers, Teachers Trainers, School Advisors: The design of a virtual lab is very important both for aesthetic, functional and educational reasons, while a "well-designed" lab can enhance the user experience. Clearly though, a good design is an absolutely subjective issue and different types of users might have different expectations from the same environment. The knowledge of the different expectations of each individual user or each segment of the users' community is very crucial for the decision making process regarding the design of several aspects of a lab. Importantly, ENVISAGE will provide designers with a means to break the "design-fail-guess-redesign" cycle and obtain a "design-test-redesign" cycle, which is more cost-effective, less risky and more mature strategy. This community includes mainly teacher trainers (heads of Science Teachers Professional Development Centres) and school advisors (Educators with very high qualifications and many years of experience who are coordinating networks of schools and supporting them through pedagogical guidance)

Teachers: Although teachers are often also the designers or even the developers of a virtual lab, we distinguish them because this is not always the case. From the perspective of a teacher, student behaviour metrics monitored in a constant basis provide insights directly into their knowledge cycle. Offering a semi-automatic way for compiling and understanding student behavioural data will reinforce attitude sensing and provide learning strategies with flexibility to adapt to the changing demands of students.

Learners Community: Students metrics allow for monitoring the student needs and address their concerns, locate trouble elements, and generally take better care of the learning process. The most commonly used ways to acquire community metrics are via online surveys, questionnaires, through mail, etc. Instead, ENVISAGE will enable continuous monitoring and high-level understanding of learner metrics providing schools with a means to reflect to the implemented approaches. This will ensure the provision of useful and interesting feedback to the students and determine the appropriate retention plans accordingly.

Teacher perspective: Certain types of user data have the potential to provide crucial information about the strong and weak points of learning environments or what causes a student to visit or revisit a virtual lab and inversely what causes students to churn out, and therefore can facilitate the improvement of several aspects of the lab, e.g., interface, through for instance an iterative testing approach, which compares different versions of a virtual lab. This can be further reinforced through the visualization of analytics results so that data are better comprehended. For instance, they could be taken into consideration in order to avoid certain design features that lead to undesirable situations, e.g., buttons that cause frustration to students. Examples of such types of data comprise for instance data conveying information about which parts of the lab are the most active and which are systematically ignored by the students. User data could also be used to help teacher recognize similar patterns in students' behaviour, categorize or segment students and treat them accordingly.

Student perspective: The main problem that arises in the context of optimizing virtual labs from a student perspective is to provide personalized goals to each individual student in a dynamic difficulty adjustment manner. These goals could be either short-term or long-term and must take into account measures like the previous level of difficulty, the required time to accomplish a task and the different attributes regarding the task. In this context, it is important to offer for instance goals that students should be able to reach without difficulty, but at the same moment, they should be on the edge of their possibilities so as to gradually improve their performance. In the same vein, it would be also useful to find students with similar characteristics and almost equal performance, and suggest optimal goals to the targeted student based on the early progress and results from the other similar users.

1.4 The scope of the current document

The scope of the current document is twofold: The first part of the document (Chapter 2) aims emphasize the potential of the ENVISAGE education approach on creating opportunities for deeper learning in science. We are describing the main characteristics of teaching for deeper learning and we highlight the areas where ENVISAGE could demonstrate significant added value. To do so the rest of the document (Chapters 3, 4 and 5) describes the evolution of 5 virtual labs (described in D1.1) through the ENVISAGE iteration process described in Figure 1.1. More specifically the document describes three categories of improvements and optimizations to the use of existing virtual labs in the form of educational scenarios. These scenarios will offer the opportunity to the project team to highlight the potential of the ENVISAGE concept: a) the enrichment of an existing widely used virtual lab with deep analytics, b) the integration of three existing labs in a common environment, and c) the extension of an existing lab to more complex real-life environment where numerous experimental activities can take place.

2 Teaching for Deeper Learning

2.1 The characteristics of Teaching for Deeper Learning

There are a variety of laboratory-based instructional approaches that engage students and allow them to think critically and solve complex problems; work collaboratively; communicate effectively; incorporate feedback; and develop the academic mindsets necessary to direct their own learning and master core academic content. These approaches hold a unique potential to foster deeper learning outcomes that empower students and develop the knowledge, skills, and abilities they will need for college, a career, and life. Although these instructional approaches engage students in different ways, the experimental work (as well as the environment physical or virtual) has to have a series of characteristics that will engage students more effectively and will guide them through the steps of the scientific methodology. Such instructional approaches could offer opportunities for deeper learning. Deeper learning leaves behind the "anemic texts, talk lectures, and fill-in-the-blanks workbooks of an earlier age" and moves teaching and learning toward an environment rich with opportunities to understand and use complex materials, communicate incisively, plan and organize their own work, solve mathematical and scientific problems, create ideas and products, and use new technologies in all of these pursuits. In the framework of the ENVISAGE approach we are trying to demonstrate that the ENVISAGE tools can help teachers to offer deeper learning opportunities to their students. "*Deeper Learning: How Eight Innovative Public Schools are Transforming Education in the 21st Century*" (2014) by Martinez and McGrath identifies six strategies and pedagogical practices common across the schools committed to deeper learning outcomes for students. Their analysis found that in order to prepare students for success in the 21st century, teachers must:

- Empower students as learners
- Contextualize knowledge so it is coherent
- Connect learning to real world experiences
- Extend learning beyond the school
- Inspire students by customizing learning experiences
- Purposefully incorporate technology to enhance (not automate) learning

Empowering students as learners

Teachers who focus on deeper learning see their first responsibility as empowering students as learners. For this reason, they use pedagogical approaches that help students become self-directed and responsible learners rather than passive rule followers. The centerpiece of instruction is helping students develop an understanding of learning as a complex and ongoing process that entails seeking feedback, revising work and regularly reflecting on what one has produced, as well as on the choices and decisions made throughout the learning process. "Revision toward mastery" is therefore a main feature of the culture and the language used by teachers committed to deeper learning. Teachers provide feedback, as well as opportunities for students to receive feedback from peers, reinforcing the idea that learning does not end with their first effort. Improving their work through rounds of feedback, revision and reflection encourages students to better understand the amount of effort required to produce high quality work. In ENVISAGE teaching is based on the inquiry process. Students are making a series of observations and hypothesis, they perform experiments, they analyse data and finally they communicate their results. The ENVISAGE authoring environment could help teachers to integrate different instructional practices in the 3D experimentation space.

Contextualize knowledge so it is coherent

Teachers who work to achieve deeper learning student outcomes also contextualize knowledge so it is coherent as a way to help students acquire content knowledge. Teachers use guiding questions, common themes, and big ideas to provide a context for every assignment, classroom activity, and project. Teachers are involving students in project that are relevant to them and to the local communities. Teachers also can involve students' projects related to global challenges. In addition, teachers often work together across multiple subjects to design integrated learning experiences to connect their otherwise separate subject-specific content. The ENVISAGE authoring environment could help teachers to design real-life projects and experiences for their students. In Chapter 5 we are presenting such a case through the integration of a virtual lab that is commonly used to 3D environment that simulates a real-life project.

Connect learning to real issues and settings

Teachers who focus on developing deeper learning competencies connect learning to real issues and settings in order to make it more meaningful for students. Teachers ensure that there are frequent opportunities for students to experience workplace conditions and expectations and address real world challenges and problem solving by interacting with professionals and experts in relevant fields, taking on a professional role when doing a project, or by connecting historical events to current issues. In Chapter 3 we are presenting a case where students are acting as scientists analysing real data from a research experiment while in Chapter 5 they need to make informed decisions for the development of a rural area.

Extend learning beyond the school

In addition to connecting to the "real" world, deeper learning-focused teachers find ways to extend learning beyond the school and construct powerful student learning experiences in a range of settings. As a result of long-term formal and informal relationships with local businesses, institutions, and community groups, the classroom walls drop away and the entire community becomes an annex of the school in which students have access to rich content, outside experts, additional resources, an authentic place and context for learning, and work based experiences. By using the ENVISAGE environment teachers could create "links" with research centres and facilities, experts and local communities to involve their students in real-life situations.

Inspire students by customizing learning experiences

Teachers who focus on deeper learning inspire students by customizing learning experiences. Teachers are intentional in establishing strong relationships with students for the purpose of finding what will ignite their interest to pursue their own learning. In the framework of the ENVISAGE implementation teachers are expected to use independent projects and labs to both customize learning and provide inspiration for all of their students. Chapter 4 of this deliverable describes such a case. Through the ENVISAGE authoring tools different labs and activities could be combined in an integrated project that offers a general overview of the scientific concepts under study.

Use technology in service of learning

Teachers who focus on developing deeper learning competencies use technology in service of learning. ENVISAGE teachers could purposefully incorporate technology to enhance, rather than automate learning; regularly employ technology tools to support student learning and to engage students in their own education; and shift their role away from being the sole gatekeeper to knowledge.

For teaching to shift to facilitate powerful learning experiences like the ones described above - where students are empowered and inspired and learning is contextualized, connected to real life, wired, and extended beyond school - the role of the teacher has to change to that of learning strategist. For a teacher to be a coach of learning, he or she must fluidly shift among a range of roles, including learning designer; facilitator; networker; and an advisor who coaches, counsels, mentors, and tutors depending on what is most needed to promote student learning.

Therefore, it is important for teachers to recognize that there are key conditions that support deeper learning outcomes and strategies, and that these conditions are sequential and rely on and build upon one another. The cornerstone condition is a school-wide culture that focuses on learning and promotes the belief that everyone is collectively responsible for student outcomes. These are two different concepts, and both are critically important.

2.2 Establish a learning culture

First, a learning culture must be established that values the need to learn, as well as students' need to learn how to learn, to become self-directed, and to develop an academic mindset. This culture is established or signaled most commonly through the creation of a clear and visible set of core values that are then reflected in the design of the school, the way in which students are introduced to and oriented to the school, what is assessed, and the consistent language used across the school, including what is posted on the walls. An understanding and reflection of these core values can be seen in everything from the language that teachers and students use to talk about learning to the way the school interacts with the community.

2.3 Create shared responsibility for student learning

The corresponding condition in support of teaching for deeper learning is a culture in which everyone is collectively responsible for student learning. This culture has to be purposefully established for students and teachers alike, and is most commonly developed by building relationships that ensure students are known well by both adults and peers, and that there are regular and systemic opportunities for frequent conversations among teachers, students, peers, and other adults.

2.4 Establish a culture of trust and professionalism

Furthermore, it is important to establish a culture of trust and professionalism as a condition that supports deeper learning. The shift in culture is critical to making sure teachers feel supported and empowered to take on new roles, and to ensure that daily work and interactions are aligned to the deeper learning mission. Trust empowers individuals to be their best selves and creates a sense of shared accountability between and among the staff. Shared accountability can encourage greater feelings of trust among teachers and between teachers and principals. School Headmasters who trust teachers and treat them as professionals may also invite teachers to share in the leadership of the school with them, meaning teachers have substantial influence on school-based decisions, especially around issues of teaching and learning. Teachers feel more comfortable wearing multiple hats—formally and informally assuming roles such as grade-team coordinator, teacher mentor, teacher leader, and coach. In this new paradigm, teachers also often take on responsibilities many principals save for themselves, such as hiring staff, creating school schedules, developing partnerships with out of school organizations or businesses, and even dealing with funders. In a culture of trust and professionalism, school Headmasters value their teachers' vast experiences and wealth of knowledge and want them to be active participants in the construction and tailoring of professional development. Because teachers design their own professional development, they are very engaged and work productively with their colleagues to ensure that professional development is growth-driven, collectively constructed, context specific, and embedded in the school.

2.5 Preserve time for teachers to collaborate

These shifts in culture and roles require settings that foster deeper learning outcomes and establish and respect time for teachers to collaborate. During this collaboration time, teachers can draw upon each other's expertise to design or revise meaningful learning experiences for students; address problems impacting the classroom and the school at large; and strategize how to improve their individual practice and student learning. Structured opportunities to work together can take the form of teacher-directed and school embedded professional development by peers or third parties on how to use specific pedagogical approaches. They can focus on feedback from classroom observations from instructional coaches or teaching peers on one another's teaching practices. Teachers can also use their structured time together to identify and share the technology tools, apps, or resources they have found to assess students for mastery of content and critical thinking as well as other skills and personalize instruction to meet the unique learning needs of each student.

In this chapter we have described the ENVISAGE Deeper Learning Paradigm and we have tried to summarize the main challenges to introduce the ENVISAGE project in school settings across Europe and the characteristics of teaching for Deeper Learning in order to make sure that the participating schools and teachers are fully realizing the different aspects and conditions of the proposed intervention. In the following chapters we are presenting a series of cases on how the ENVISAGE tools could enrich existing virtual labs to offer more effective and deeper learning experiences to students.

3 Virtual Lab Enrichment with Deep Analytics – Developing High-Level Problem-Solving Competences

3.1 Pedagogical Motivation

HYPATIA (Section 6.9, D1.1, http://hypatia.iasa.gr/) is a virtual lab which offers the users the ability to visualize and analyze events recorded by the ATLAS experiment at CERN. It is a lab that included high level problem solving tasks for the students. Since 2010 the online version of HYPATIA in its various iterations has been used by thousands of students across Europe and beyond. Students have to select a set of data and analyse them through a specific process in order to identify the events that contain the creation of the Higgs Boson. The performance of the student can be assessed through the final result of the activity, which is the estimation of the Higgs Boson mass. Students have to compare their findings with the experimental value measured at CERN in 2012. However, the actual student performance during the use of HYPATIA had never been monitored or assessed. In this scenario we are studying the added value of the integration of shallow and deep analytics to the HYPATIA Lab.

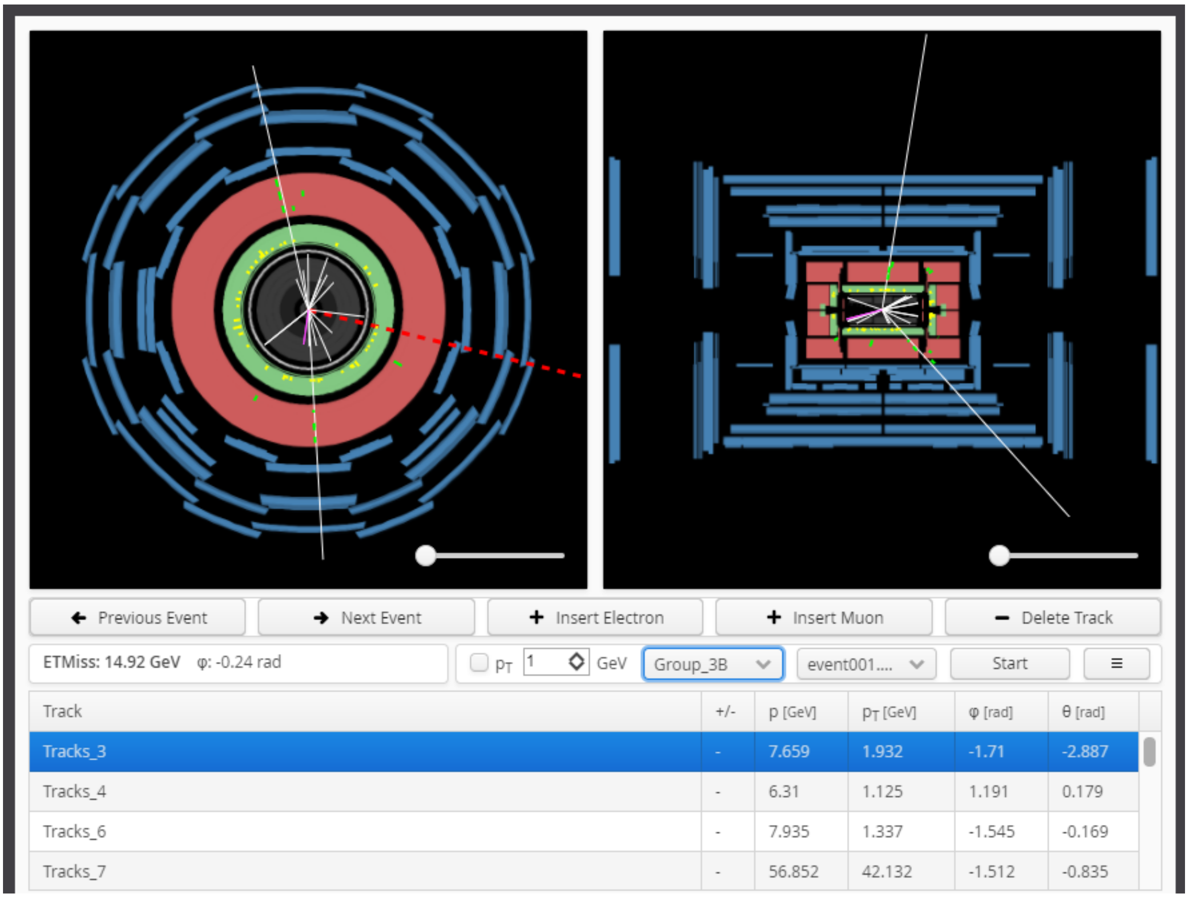

Figure 3-1 HYPATIA offers the opportunity to students to analyse real data and to discover the Higgs Bosons created through an inquiry process.

This information is crucial for the complete and thorough evaluation of student's performance. To address this shortcoming, a complete student performance evaluation system was developed and implemented in the framework of the ENVISAGE project. A series of check-points were identified during the students' interaction with the lab. A series of indicators (including both deep and shallow analytics) were proposed and tested to demonstrate the real progress of the student during the task.

These indicators were selected in order to help our team to monitor the overall interaction with that virtual lab through the different phases of the inquiry process. During the use of HYPATIA in the context of an educational scenario, the system records certain parameters of student performance. One record is created for every student. Each record is evaluated and a final score of low, *moderate* or *high* value (based on the PISA categorization of the proficiency of the problem-solving competence) is assigned to each student according to a weighted evaluation of the stored indicators. Furthermore, graphs are created in a separate page of the dashboard representing the most important of the student performance indicators. This information is a very important part of student evaluation as it gives detailed information on whether each student was able to assimilate the provided information and implement all the newly acquired knowledge in practice. It is also an invaluable tool in studying the correlation of student performance during the use of HYPATIA and in the problem-solving questions at each phase of the implemented scenario.

3.2 Proposed Indicators

In the framework of the activity, students are given a sample of thirty Z boson decay events, out of which 15 decay to muon pairs and 15 decay to electron pairs. After the students become familiar with the identification of the two Z boson body decays, they are given a sample which contains Higgs particles decaying to two Z bosons, namely four body decays. Their final aim is to identify a number of Higgs bosons. In the framework of our test students' performance during the activity was monitored by seven indicators, which cover all aspects of student investigations and understanding. The following indicators were selected by the HYPATIA development team.

- **The number of Z bosons identified by the students.** In their first exercise, the students search for Z boson decays to leptons. This indicator shows how successful each student has been in identifying those decays. Z bosons can decay to either electrons, which are harder to identify, or muons. More proficient students will identify both decay modes.
- **The deviation between the average Z mass calculated from students and its actual value**. This is an indicator of the quality of the students' results. Each invariant mass can deviate from the expected value but their average should be fairly close to it if a sufficient number of decays has been identified. A large deviation indicates incorrectly selected tracks not belonging to Z boson decays. This indicator also shows the students' understanding of reconstructing an unstable fast decaying particle by its decay products.
- **The Root Mean Square (RMS) of the Z boson masses.** This is an indication of the spread of results around the average value. It is very important since the average of several incorrect results can still be close to the expected value. The resulting RMS needs to be

within certain limits indicating that all selected invariant masses actually correspond to Z bosons.

- **The ratio of Z decays to electrons over decays to muons.** Z to muon decays are much easier to identify because of the appearance of muon tracks that is unique. However, the actual decay to either mode has the same probability and so the expected result is a value as close to one (50%/50% ratio) as possible. Proficient students approach this value while weaker ones tend to favor muonic decays.
- **The number of Higgs bosons.** In their second exercise the students look for Higgs boson decays to four leptons. This indicates how successful they have been in their search. Each Higgs decays to two lepton pairs so in total there are three possible combinations. Students need to be able to identify all of them in order to discover all Higgs decays. Furthermore, they have to understand that the sum of the charges of all four daughter particles have to be zero.
- **The number of interactions** between the student and the user interface of the application. We believe that a proficient student will perform his analysis with a smaller amount of interactions than a poor one. This is because he will take the proper actions and not have to go back and correct his work. This indicator is not currently used in the final score as we are evaluating our hypothesis of correlation between it and overall student performance.
- **Total exercise duration.** If students are given sufficient time for most of them to complete both exercises, we believe that the better ones will require less time.

The value of each indicator contributes to the final result according to its assigned weight. Calculation of the final result is performed at the end of each intervention. This allows the adjustment of the calculation formula for all records regardless of whether they were inserted before or after the alteration. The weights used in the final evaluation for each parameter are currently under consideration as we are gathering more data and studying the correlation between the various parameters and the comparison with the problem-solving questionnaire.

3.3 Analysis of the Results

In the framework of the pilot implementation, 86 students participated in the activities. Overall six pilot implementations took place in the framework of school-based activities (during the lessons or during the project work. The Inspiring Science Education portal (portal.opendiscoveryspace.eu/ise) was used for the tests. The portal hosts numerous advanced educational scenarios and a delivery environment through which every student can implement the proposed activities[1]. The system includes an integrated assessment mechanism that provides the proficiency level in problem solving competence for every student and for the whole class (class profile). In this framework we were able to perform a series of comparisons between the data collected during the implementation of the overall activity (about 2 hours) though the existing assessment mechanism and the data collected during the use of the lab (about 1 hour and 20 minutes) though the assessment scheme

[1] The educational scenario used is available here: http://tools.inspiringscience.eu/delivery/lesson/previewLesson?id=41fbf7bc710a470aa531911f744973cf&t=p&uname=PREVIEW

described above based on the selected indicators. Figure 3.2 presents the results according to the Inspiring Science Education portal. According to the results 43.5% of the students have shown high level of proficiency in problem solving tasks, 24.1% of the students have shown low level of proficiency in problem solving tasks and 32.4% of the students have shown medium level of proficiency in problem solving tasks. Figure 3.3 presents the same set of data distributed to the four different phases of the inquiry process (Orientation and Asking Questions, Hypothesis Generation and Design, Planning and Investigation, Analysis and Interpretation). Figure 3.4 presents the time distribution over the four inquiry phases.

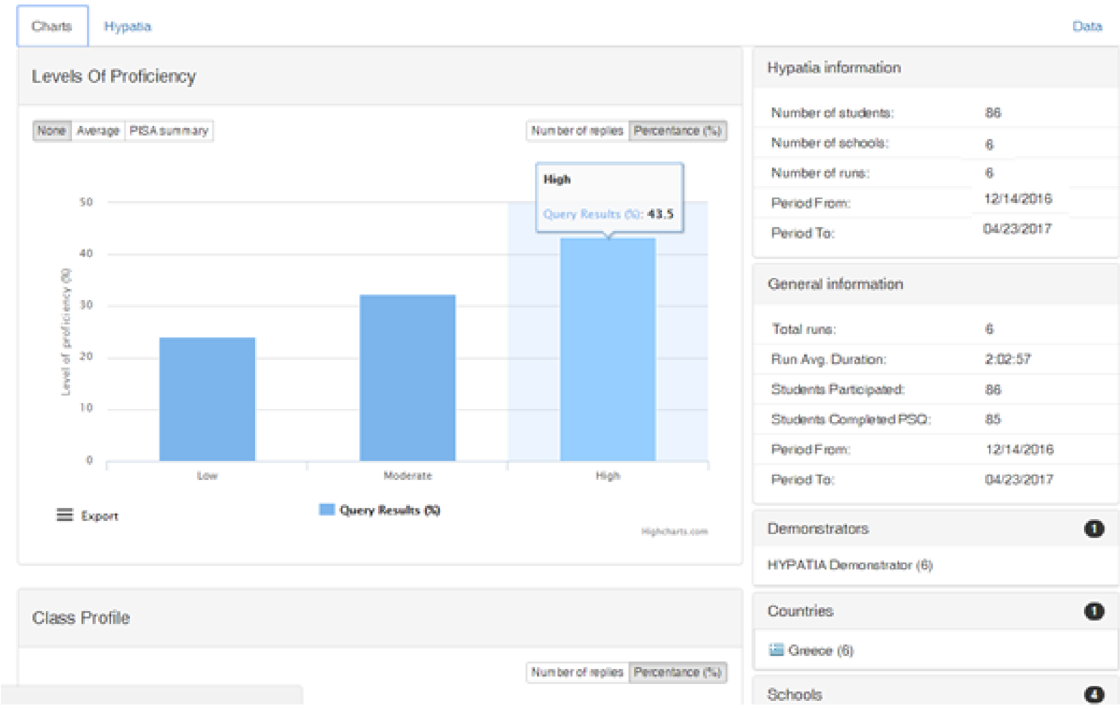

Figure 3-2 The Inspiring Science Education dashboard tool presents the data of the 6 pilot implementations with the involvement of 86 students. The average duration of the activity was 2 hours while 85 students have provided data through the portal mechanism. This o

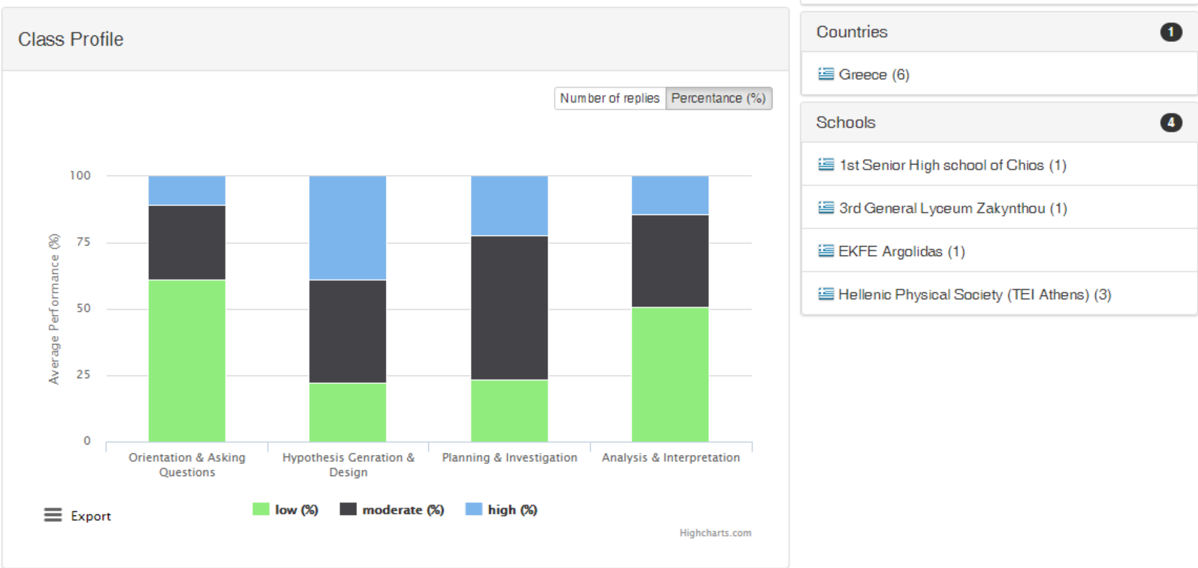

Figure 3-3 The Inspiring Science Education dashboard tool presents the scores of the students during the four phases of the inquiry cycle. The graph demonstrates that more than 50% of the students have shown medium level of proficiency in Planning and Investigation

According to the data from the pilots it took on average 1 hour and 20 minutes to the 86 students to realise the third phase that includes the use of the HYPATIA Lab.

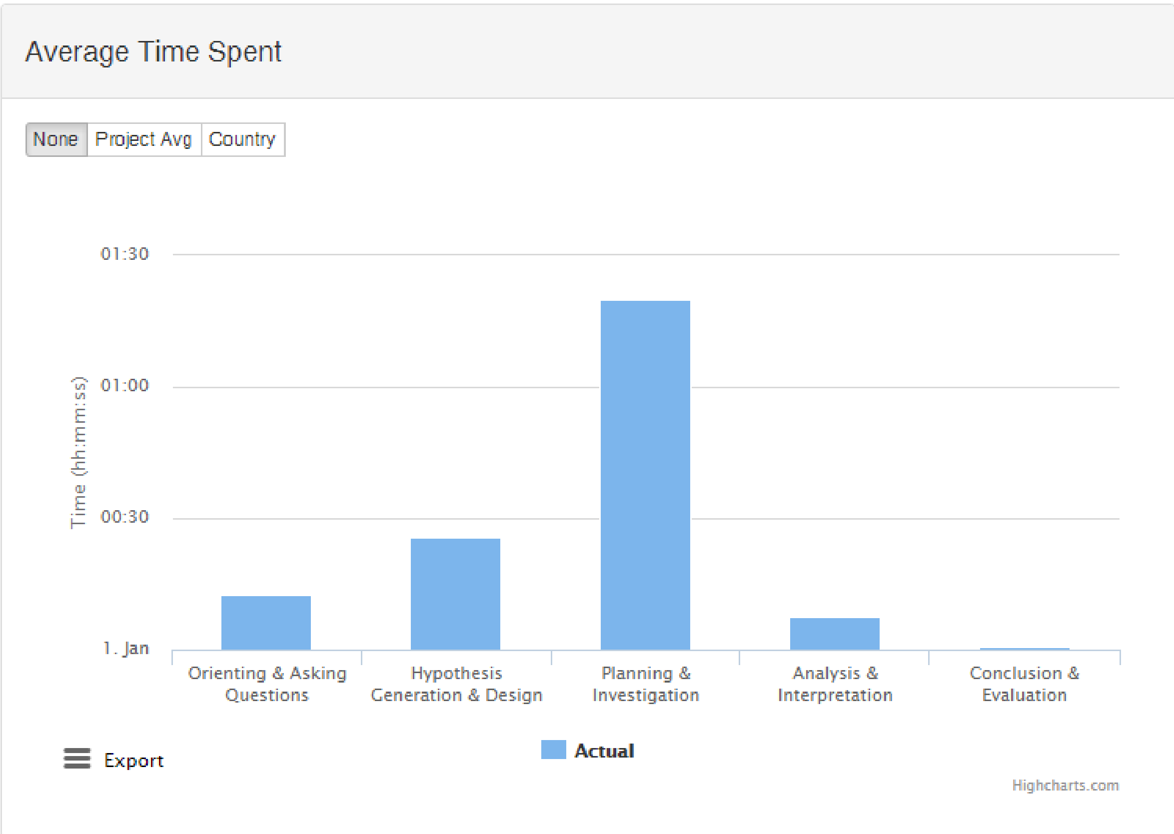

Figure 3-4 The graph presents the time distribution of the educational activity over the four phases of the inquiry cycle. The third phase dominates the time allocated to the implementation of the educational scenario.

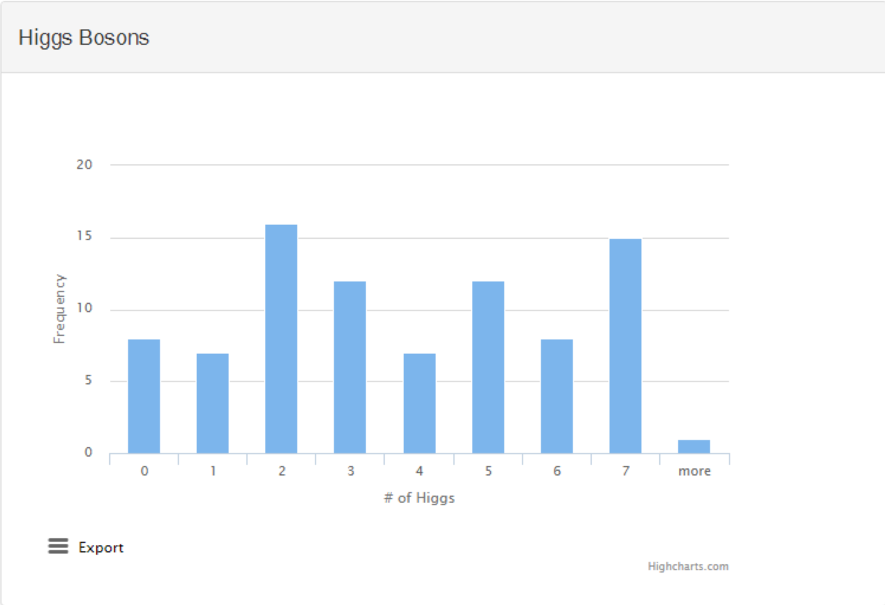

Figure 3-5 The graph presents the number of Higgs Boson which were successfully identified by the students involved in the activity.

By implementing the indicators that were developed in the framework of the ENVISAGE project we have managed to monitor the progress of the students during the use of the HYPTIA lab during the third phase of the intervention (see for example Figure 3.5). By characterizing the value of each indicator for each student we were able to create classroom profiles similar to the ones presented in Figures 3.2 and 3.3. Figure 3.6 presents the average classroom profile for all students involved in the activity. According to the results 37.2% of the students have shown high level of proficiency in problem solving tasks, 24.4% of the students have shown low level of proficiency in problem solving tasks and 38.4% of the students have shown medium level of proficiency in problem solving tasks. This result is quite close to the results produced by the Inspiring Science Education assessment mechanism.

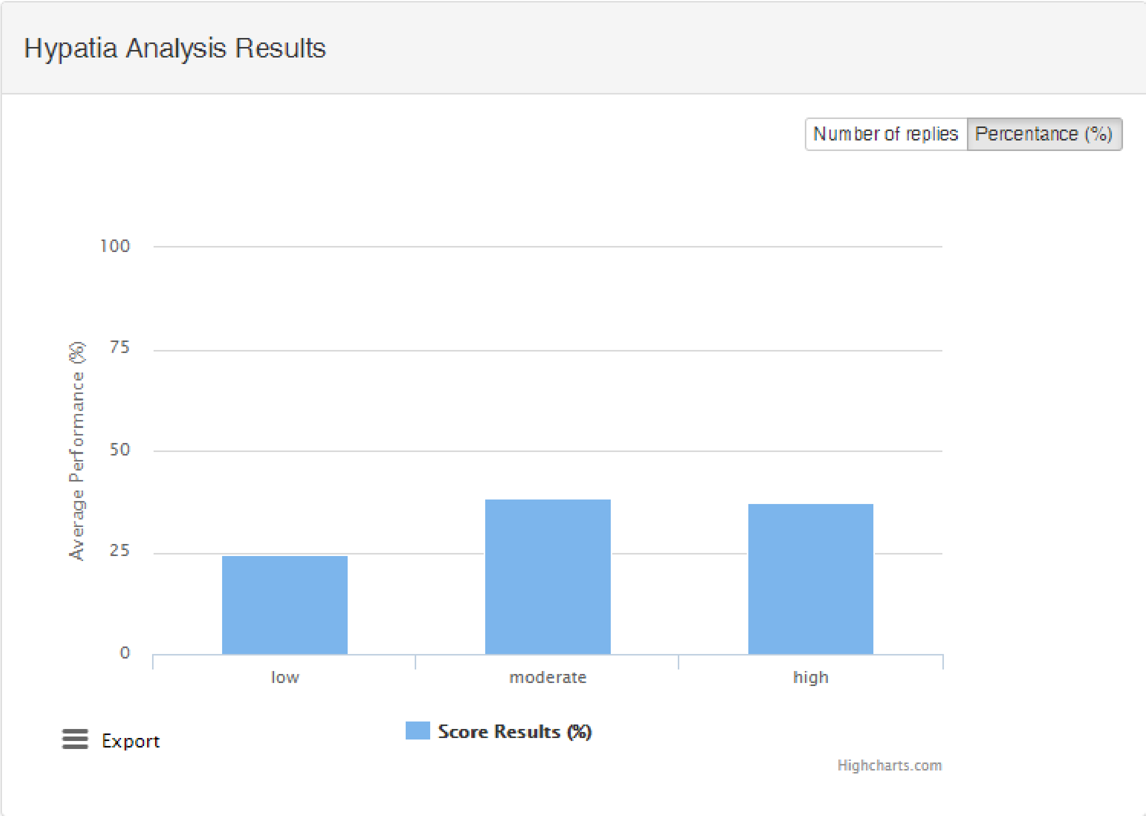

Figure 3-6 The classroom profile for all students involved in the activity based on the data collected through the ENVISAGE mechanism. According to the results 37.2% of the students have shown high level of proficiency in problem solving tasks, 24.4% of the student

Table 3.1 presents the results from the Inspiring Science Education assessment mechanism (overall classroom performance and classroom profile) and from the in-depth monitoring of students' tasks during the use of the HYPATIA lab. It has to be noted that the Inspiring Science Education assessment method is a quite complex and demanding process for the teacher as the problem-solving questions have to be developed according to the educational scenario and harmonised with the PISA standard values. The specific questions that were used for the scenario that was implemented in the framework of the ENVISAGE pilot have been tested with numerous students in different European countries the last 3 years. So, we consider that are offering a valid reference for the reliability of our test. According to our findings the in-depth monitoring process (although it was tested with a small number of students) it offers a quite good estimation of the classroom profile. Our effort during the second pilot will be to optimise the values of the indicators in order to harmonize the results with the expected values according to the standard assessment method.

Table 3.1 Comparison of Results

Problem Solving Proficiency Level	Overall Classroom Performance based on PISA assessment method (%)	In-depth monitoring of students' tasks while using the lab (%)
High	43.5	37.2

Medium	32.4	38.4
Low	24.1	24.4

3.4 Technical Characteristics of the HYPATIA Virtual Lab

The HYPATIA Virtual Lab and Event Display uses the Vaadin web application development framework. This allows most of the application to be written in Java while the UI uses the Vaadin libraries (https://vaadin.com/home) which are based on Google's GWT (http://www.gwtproject.org). Additional theming for the application is written in CSS. HYPATIA is packaged as a servlet and deployed as a Java Web application hosted by Apache Tomcat. It communicates with the MySQL database used to store the student indicators through JDBC. The UI is rendered in any browser using standard web technologies javascript, HTML5 and CSS all of which is server-generated on demand. This allows for easy deployment but also ensures that the application can be used on any platform irrespective of locally available resources. HYPATIA is interlinked with the Inspiring Science Education Dashboard which reports the implementations of the educational scenarios hosted on the portal. The dashboard is responsible for periodically harvesting and integrating data from the HYPATIA database. This data is correlated with the appropriate runs/schools and the final evaluation score is calculated with a parametric algorithm. A new UI was created for the HYPATIA demonstrator that includes additional graphs for the indicators, rendered using highcharts (https://www.highcharts.com). The dashboard uses Node.js (https://nodejs.org/en), HTML and CSS making it useable on any browser.

4 Developing an Integrated Lab Environment for Schools

Introductory and general education STEM courses can be challenging for non-science majors, who often view science as a static body of facts. Laboratory experiences are intended to involve students in science, but frequently, due to a variety of resource, safety, and support constraints, the wet lab can become a “cook-book” activity. Lack of engagement and opportunity for creativity may be reasons why some students perform poorly in these courses. One of the advantages of virtual labs is that they provide a risk-free environment for students to explore scientific concepts in an inquiry-based fashion. Using virtual labs, students can formulate hypotheses and carry out experiments where “mistakes” can be made, and the knowledge gained from their attempts can be used to modify experiments toward the desired outcome. This mode of learning by doing is one of the main reasons virtual labs have been designed for use in science courses and more specifically in chemistry experiments. Virtual labs can also provide active learning opportunities for general education students to “achieve an understanding and appreciation of scientific principles and the scientific method”. Virtual Labs can be integrated with in-class lectures and, when used with a hybrid-flipped lab model, with two tracks of online and in-person labs alternating every week, have the potential to increase student learning and positive attitudes towards science while simultaneously reducing bottlenecks. Once labs are online, faculty and students are freed from the equipment and scheduling constraints of the brick-and-mortar laboratory.

4.1 Pedagogical Motivation

A major lack in much current science instruction at the school level is appropriate active learning experiences. Students in many science courses still get too few opportunities to think and reason about scientific problems. Well-designed laboratory experiments provide the best means to give students the opportunity to learn about a science subject while developing the thinking skills most instructors have as a goal of their course. However, there are many limitations on the use of real laboratory experiments in a high school science course. Students in educational labs are severely limited by the time required for most serious investigations. A typical laboratory for a chemistry class will meet once or twice a week for two to three hours each time. This time constraint is a major barrier for introductory students as they try to learn how to be a scientist. Many important chemical experiments take weeks, months or years to carry out, putting them well beyond the reach of the typical teaching laboratory. Many other barriers limit the choice of experiments in teaching laboratories, including a lack of appropriate equipment, insufficient funds for expensive reagents, restrictions on the use of hazardous chemicals and radioactive materials, a lack of technical skills by the students and ethical concerns.

As a result of these difficulties, most teachers either concentrate on using laboratory time to provide students with an opportunity to practice being a scientist by carrying out inquiry based investigations, or demonstrate scientific principles by having students carry out carefully controlled experiments designed by the instructor. In both cases the main mechanism for students to learn the subject is the traditional lecture. A major trend in current attempts to improve science education is to try to replace static lectures with more active learning approaches. While there are many versions of "active learning," in the sciences an inquiry approach is frequently used. One version of this is the learning cycle method in which students explore a chemical phenomenon before receiving any explanation from the teacher. Other aspects of the inquiry approach include having the students propose their own hypothesis and design, execute and interpret their own experiments to test their hypothesis. In addition to learning how to think like scientists, students learn the concepts and facts of a subject better when they have to apply the knowledge. While there are many ways to make the lecture more inquiry based, one very useful alternative is the use of simulations.

To address these problems, in the specific scenario, the ENVISAGE project is creating an integrated environment by combining simulations of chemical experiments and phenomena that can be used to supplement traditional laboratories and lectures, providing students with many more opportunities to learn by experimentation than is possible using traditional methods. Eliminating the time constraints of the traditional experiment, the simulations give students the opportunity to design and interpret experiments, to learn from their mistakes, and to revise and redo their experiments just like real scientists. The simulations are not designed to replace the traditional "wet labs" found in an ideal chemistry course, but rather to extend the laboratory experience to subjects and experiments that cannot normally be done, or not done well enough, in a traditional laboratory. The simulations are also *not* multi-media presentations, stand-alone tutorials or on-line courses. A key advantage of a simulation is the potential of allowing the student to design and carry out many more experiments than would be possible with real labs. This gives the student many more opportunities to practice the skills of hypothesis creation, experimental design and data analysis than can happen in the normal lab or lecture setting. A lack of underlying complexity is a problem with many of the currently available online educational simulations, which frequently allow only one real experiment. Thus, one of the design goals for the EVISAGE project is to create simulations with enough underlying complexity that students would be able to do many different experiments (see the proposed list of Virtual Labs in Section 6, D1.1).

Figure 4-1 The ENVISAGE virtual lab environment that could host the realization of numerous experiments which require different labs and simulations.

In addition to the complexity in the starting parameters, each of these labs operates stochastically, so that even with identical starting conditions students will get different results. The large number of possible experiments and the speed at which each experiment can be carried out, five to ten minutes per experiment, means that students can get much more practice at designing and interpreting their own experiments than is possible in the traditional laboratory. This creates new possibilities for teaching some topics as students can now figure out the underlying principle on their own, with only minimal guidance from their teacher.

4.2 Current Status

Currently we have integrated three Chemistry Labs to the integrated Lab environment. A short description of the labs follows:

- **Atomic orbitals**. Atomic orbitals are mathematical functions that describe the properties of electrons in atoms. Using this lab, students learn how to build atomic orbitals according to the general principals involved and they will be able to visualize their shapes.
- **Build Inorganic Molecules.** The lab will help students learn how to build inorganic molecules. They will also be able to investigate the nature of the bonds between the atoms and how are electrons placed.
- **Molecule Builder.** Using the Molecule Builder, the user explores the properties and nature of 20 different molecules or compounds. This resource is spread across 4 linked sections:
  - Select a molecule and associate it with a homologous series
  - Associate the homologous series with a functional group
  - Chose a structure map for your molecule
  - Build the molecule from various elements

The ability to carry out many different experiments is a key to making this work, as that is the only way the students can eliminate many of their initial explanations for what is happening. Even for the many students who fail to solve this problem, the experience is very helpful, making them much more attentive when the genetic explanation is given in class.

4.3 Future Plans

Another goal of the ENVISAGE approach is to design simulations that could be used to learn about key concepts in Chemistry that are not normally used in traditional laboratories because of time, expense, hazards, etc. In the next phase of development of the Chemistry lab we will investigate examples of labs which simulate processes that take place over hundreds of years; which simulates experiments that use toxic chemicals; which simulates the use of radioactive isotopes; which simulate the use of complicated and expensive measuring equipment. With the rapid increase in the computing power available to students and the increased familiarity of students with using applications over the Internet, on-line tools such as the simulations produced by the ENVISAGE Project will become more and more useful. Simulations such as these provide new tools to increase the use of the inquiry approach to teaching science. They will not, and should not, replace real hands-on laboratories. Finding the right balance and the proper way to use these new tools is going to take some time and experimentation by teachers. Hopefully, they will at least consider the possibilities these new tools provide.

5 ENVISAGE in Action: From Virtual Labs to Real-Life Projects and Activities

This scenario aims to expand the use of the Wind-Energy simulation to a complex real-life project. It includes hands-on, critical thinking activities that help secondary students to develop a comprehensive understanding of the scientific, economic, environmental, technological, and societal aspects of wind energy.

5.1 Pedagogical Motivation

The issue of knowledge transfer, i.e., transferring learned concepts to practical applications, is a widespread problem experienced in secondary education (van Gog, Kester, & Paas, 2011; Day & Goldstone, 2013). This predicament is visible across domains and limits the ability of secondary education to prepare students for problems they will face as professionals. Students can often fail to apply knowledge learned in the classroom setting to real world problems. The students retain the classroom knowledge, but do not recognize when it is appropriate to apply in situations outside of school (Kalyuga, Renkl, & Paas, 2010; Meissner & Bogner, 2012). In the framework of the ENVISAGE project we are developing an advanced simulation game that aims to introduce students to the inquiry process while at the same time will help them to implement their knowledge in real-life problems. The main task of the students in this game would be to set up and operate a Wind-Farm to support their local community.

5.2 The Wind-Farm Challenge

In the framework of this scenario students leave in a rural community that is growing and needs to explore options for adding electricity generation facilities to support the local demand and development. One of the opportunities being considered is from a developer to build a wind farm on land in the community. Students understand that developing renewable resources is a way to meet the growing electricity needs of their area, but they are curious about the impacts a wind farm might have on their community versus a natural gas plant or a solar farm. They will need to interact with other stakeholders that have been invited to present their perspectives at a public forum. Based on their research, followed by their panel presentation, the community will vote on whether or not to support building the wind farm. Through this process the students are introduced in the inquiry process. More challenges are now to come.

a) **Students have to analyze the financial impacts.** The community has consulted an economist, a person who can analyze the financial impacts of actions. They have asked him/her to determine the costs of generating electricity from fossil fuels and wind energy and to do a comparison study. This includes comparing construction costs, transmission costs, generation costs, and potential tax credits available for using wind. 1. How does the cost of using wind to generate electricity compare to other sources? 2. What economic advantages/disadvantages would the wind farm bring to the area? 3. Will the wind farm impact the economy of the area by bringing more jobs to the area? How many jobs? Will the jobs be permanent? What training is required?
b) **Students have to decide on the exact location of the wind farm**. As the developer of the wind farm project, students must create a plan that details the advantages of

establishing a wind farm in the particular area. They will need to investigate the characteristics of the different proposed locations (e.g. next to the sea side or up to the mountainous area that is located at a small distance from the community? – See Figures 5.1 and 5.2). Students must also be able to answer questions from those groups that might oppose the wind farm. It is important within the local community students understand the "big picture" of the positive and negative impacts of developing the wind farm. 1. What are the economic and environmental benefits to the community of developing the wind farm? 2. What are the disadvantages? How will potential risks be minimized? 3. How will the environment be protected during the installation, operation, and maintenance of the wind farm? 4. How will the utility and its customers benefit from the addition of the wind farm? The site planner of a wind farm considers many factors to determine the best location for a wind farm. Students must take into consideration the important concerns that community members have. They need to determine the optimum areas for the turbines in regard to local weather patterns (wind strength). They must also take into consideration any other environmental factors that might affect the siting of the wind farm. 1. What information about local and global wind patterns and wind technology must they research before siting a wind farm? 2. What other weather information might be important besides wind speed? 3. What other factors must they consider? Are there roads and power lines nearby? 4. What environmental factors must they consider before siting a wind farm?

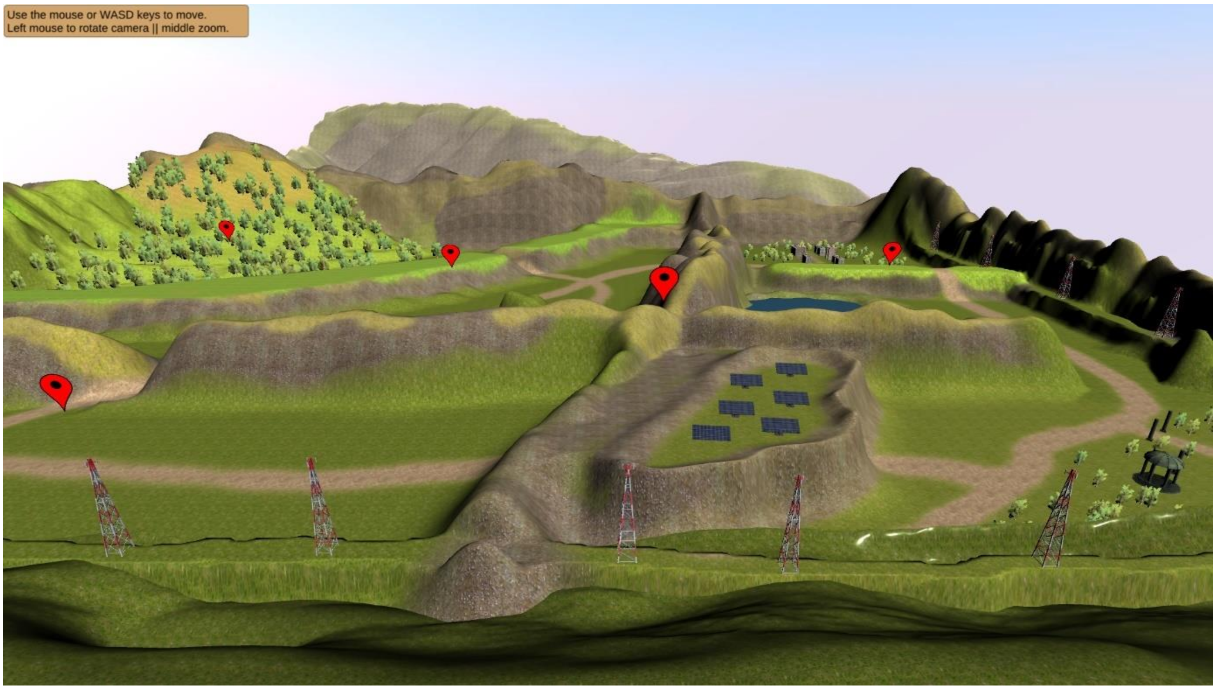

Figure 5-1 The ENVISAGE Wind-Farm Challenge asks from the students to make decisions for the installation of a Wind-Farm in their rural community. Among the challenges they will need to deal with in the framework of the game is the selection of the most appropriate location. The different options are interlinked with a specific rationale that will be used to categorize the students at the three different levels of proficiency of the problem-solving competence.

c) **Students have to operate the Wind-Farm to support the local economy**. Now students have the role of an employee of the local utility company and are responsible for making sure that the utility has the necessary capacity to provide electricity to all of the customers. There is increased demand for electricity in the community and students must secure reliable sources of additional generation in the near future. They would be the main purchaser of electricity from the wind farm. 1. How expensive would the electricity be from the wind farm? 2. How predictable is the electricity generation from the wind farm? 3. How reliable is the equipment on the wind farm? What happens if one turbine goes down temporarily? (see Figure 5.2) 4. Will there be additional costs to the utility company that might be passed along to consumers?

Figure 5-2 The ENVISAGE Wind-Farm Challenge includes a series of surprise factors for the students. One of them is the failure of a turbine. The frequency of failures could be increased when the turbines have to operate for long time. A rotation scheme in the operat

d) **Students have to deal with future challenges**. Now students have the role of an investor. As the community is developing it attracts the interest of some investors who have decided to finance a large hotel facility in this rural area. They are also proposing the expansion of the Wind-Farm to cover the additional energy needs. Students need to determine the costs, risks, earning potential, and benefits of investing in the wind farm.

1. How much will it cost to build and maintain the new wind farm? What costs do they need to consider? 2. How much return of income can they expect from the investment? Over how many years? 3. What are the biggest risks to investing in such a large facility in the rural area? 4. How might the risks and rewards of a wind farm compare to other energy facilities (solar or natural gas, for example)?

5.3 Future Plans

The specific scenario is expected to be implemented with 120 students in the framework of the second pilot phase. The main aim is to use the Wind-Farm game in order to assess that problem-solving competence profile. At each challenge students will need to make specific decisions. According to their decisions they will be characterized as high, medium or low achieves as far as the problem-solving proficiency is concerned. Based on their decisions at each challenge we will get an overview of their overall performance during the game.

6 Conclusions

In this phase of the project we have defined the stakeholders involved in a learning situation involving virtual, online learning environments such as virtual labs, focusing on the teachers and students. Based on the proposed framework the project team has selected a series of virtual labs and performed an analysis of the reactions of the stakeholders during a series of real-life pilots. In total eleven pilots were conducted for the first iteration of the ENVISAGE services. Overall, the users evaluated the labs with positive feedback. They liked the content and believed the proposed labs should give the students a deeper understanding of the subject. The also clearly saw the learning goals of the labs. Based on the stakeholders' feedback we are presenting a series of updated educational scenarios that will serve as prototype demonstrators for the second pilot phase of the project, emphasising the added value of the ENVISAGE concept to the design of more engaging activities that promote the development of proficiency in problem solving competence. These scenarios are presenting three different cases that according to our view will offer the opportunity to the project team to highlight the potential of the ENVISAGE concept a) the enrichment of an existing widely used virtual lab with deep analytics, b) the integration of three existing labs in a common environment, and c) the extension of an existing lab that was used during the first pilot phase to more complex real-life environment where numerous activities can take place. These scenarios (along with the requirements to be presented in D1.4) will feed into WP5 for specifying the virtual labs to be designed and developed using the authoring environment (WP4) and will provide the test bed for evaluating the effectiveness of the developed technologies in WP2-4 to address the stakeholder requirements.

7 References

ENVISAGE Deliverable D1.1 – Educational scenarios and stakeholder analysis http://mklab.iti.gr/envisage/lib/exe/fetch.php?media=d1.1-educational_scenarios_and_stakeholder_analysis-final.pdf

ENVISAGE Deliverable D1.2 – Data structure and functional requirements http://mklab.iti.gr/envisage/lib/exe/fetch.php?media=d1.2_datastructurefunctionalrequirements_final_v5.0.pdf

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