# An Approach to Advance STEM Education Practices Based on IoT Technologies and the CoPs Paradigm

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**Abstract.** Internet of Things and other state-of-the-art technologies like mobile and ubiquitous computing present ample opportunities for developing novel solutions almost in every domain of modern life. The research work presented here aims to leverage on the potential of such technologies in the direction of enhancing learning practices in secondary level education and promoting positive attitudes towards the corresponding scientific and engineering disciplines. The originality of the proposed approach lies on the provision of an educational platform, framed by contemporary pedagogical principles, and with an aim to stimulate collaboration between the relevant stakeholders in the form of operational communities of practice. Such communities are brought together on the basis of participating in on line activities, problem solving, exchanging reflections and experiences in the context of educational scenarios that incorporate modern technologies. The platform development is discussed in terms of the underlined conceptual models, the defined stakeholders' requirements, the online services developed, the software tools integrated and the data management supported. An example educational scenario, the corresponding IoT application developed and preliminary evaluation results of this approach are also reported.

**Keywords:** Internet of Things · Ubiquitous computing · Communities of practice · UMI technologies · STEM education

## 1 Introduction

Currently, there is a growing body of research about emerging technologies, such as, ubiquitous computing, mobile computing and the Internet of Things (IoT), collectively mentioned in the literature as UMI technologies [1]. Despite the many challenges that


B. M. McLaren et al. (Eds.): CSEDU 2018, CCIS 1022, pp. 1–25, 2019.
https://doi.org/10.1007/978-3-030-21151-6_7

must be overcome in terms of lack of standards, service adaptation, privacy and trust concerns [2], it is considered that the proliferation of these niche technologies may offer a wide range of learning opportunities, especially in the context of Science Education [3]. Undoubtedly, such technologies can be used either as educational subjects or as facilitators of the educational practice [4].

In parallel, there is a growing market need for jobs that fall within this professional domain. An analysis of Eurostat data on STEM employment indicates that in the next ten years, there will be 8 million new STEM jobs in the EU [5]. However, an argument is where the designers and developers of these technologies and related products will be educated and with what skills and training programs.

The UMI-Sci-Ed (Exploiting Ubiquitous Computing, Mobile Computing and the Internet of Things to promote Science Education) is a Horizon 2020 project (http://umi-sci-ed.eu/) related to the EU work program "Innovative ways to make science education and scientific careers attractive to young people" aiming to provide efficient practices into this technology training issue. UMI-Sci-Ed approach is to introduce several model educational scenarios that incorporate UMI technologies, in order to cultivate relevant competences to high school students. The core objectives of the project are stated in terms of delivering:

- Novel educational services – the aim is to develop and evaluate a training mechanism for UMI to help students acquiring relevant competences.
- Career consultancy services - the aim is to develop and sustain Communities of Practice for UMI and materials to motivate students pursuing a career in related domains.
- Supporting software tools, through the development of an online platform.
- Supporting hardware tools, through the delivery of a dedicated hardware kit.

In the context of UMI-Sci-Ed, UMI technologies are introduced in the learning process of secondary schools' students (i.e. 9th and 10th grade). In particular, the students attend to specially designed learning activities concerning UMI technologies under the guidance of the *Communities of Practice* (*CoPs*) paradigm [6]. The proposed methodology adheres to a number of robust educational principles. Firstly, in order to bond theory with practice, students are encouraged to develop technology-based applications acquiring thus an "attitude of creation". Secondly, by exploiting the UMI-Sci-Ed platform on-line services, students exchange material, results and good practices with other members of the community disseminating and reflecting upon important information. Thirdly, by following contemporary pedagogical approaches that promote active learning practices in a structured way promoted by proper educational scenario models.

The students are invited to explore IoT technologies through hands-on activities. The principal tools that are used are advanced System on Chip boards like the UDOO Neo board (https://www.udoo.org/udoo-neo/) and the Raspberry Pi board (https://www.raspberrypi.org/) (Fig. 1). Both offer a versatile sensor kit and wireless communication allowing high performance at a low price and enabling the creation of various IoT applications.

Given the pivotal role of CoPs, emerging learning and consequently the knowledge is constructed by interactions and communications between the relevant stakeholders.

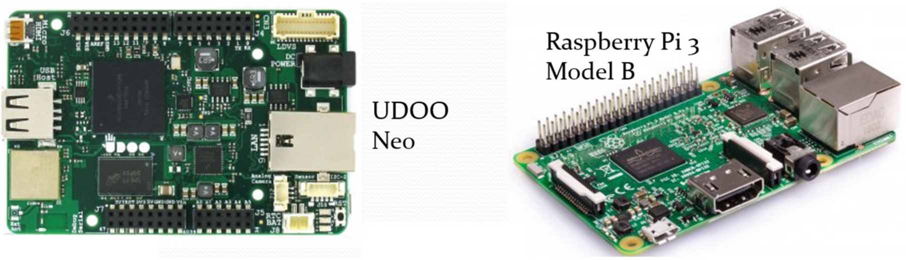


**Fig. 1.** IoT technologies for hands-on activities in UMI-Sci-Ed.

Under this scope, the UMI-Sci-Ed platform aims to bring together practitioners, students, school teachers, instructional designers, academics and IT specialists, who actually are going to act as members of the UMI-Sci-Ed CoPs. Such communities are brought together on the basis of participating in on line activities, problem solving, exchanging reflections and experiences in the context of educational scenarios that incorporate UMI technologies, in order to cultivate relevant competences.

An example of educational scenario and application using IoT technologies is discussed in this chapter whereas the members of the assembled CoP included students, teachers, and technology/domain experts with a mentoring role. UMI experts who involved originated from the postgraduate program on engineering of pervasive computing systems of the Hellenic Open University [7].

The remainder of the chapter is organized as follows. In the next section a discussion on related work is provided and the distinction of our approach is argued. The background conceptual models that underpin the development of the UMI-Sci-Ed platform is discussed in Sect. 3. The role of CoPs theory and the devised UMI-Sci-Ed Educational Scenario Template in shaping the UMI-Sci-Ed platform operational characteristics are explained. The UMI-Sci-Ed platform development is discussed in Sect. 4 in terms of user requirements, on-line services developed, software tools integrated and data management. We discuss also the platform architecture and the main modules that support the involvement of the stakeholders. Next, we present an example educational scenario, the corresponding UMI application developed, and report on preliminary evaluation results of this approach. Finally, we provide our conclusion and future work.

## 2 Related Work

The multifaceted nature of UMI-Sci-Ed platform to promote science education creates an intersection between different tool areas such as online CoPs management, computer-supported collaborative learning (CSCL), learning management systems (LMS) and IoT platforms. Although there is no complete match of each of the above tool areas with the aims of the UMI-Sci-Ed platform there are certain aspects of the respective field that have been encapsulated in the developed platform.

Although it is quite frequent phenomenon that social networking tools (i.e. Facebook, Twitter etc.) are used to build online CoPs, on the other hand, it is not common to identify general purpose platforms that address the needs of any CoP [8]. In this context the tendency is that CoPs platforms are built on demand for specific domains, or CoPs members use one or more different tools according to the task at hand (e.g. DISCUSS, Twitter, YouTube, Moodle, wikis, and forums).

In response to the popularity of Web 2.0 technologies, LMSs evolved to include features such as blogs and wikis [9]; it has been recognized, that the majority of LMSs introduced friction for instructors, trying to reuse and share course materials. To adhere to these market needs, tools for establishing collaboration between software community members so as to process code or software development material, have been recently introduced and developed, such as GitHub [10]. Environments as such provide social and collaborative features in conjunction with distributed version control. GitHub is a popular Web based social code sharing service that utilizes the Git distributed version and control system. The rationale of circulating educational material and collaborating on this basis for further developing software applications is quite important in an effort to develop a culture of collaboration, transparent and active, for teachers, practitioners, and educational policy makers involved in this creative and dynamic process.

Lamer et al. suggest the use of robotics as an enabling ICT platform for promoting STEM education [11]. The multidisciplinary nature of the robotics field offers the opportunity for young children to enhance their creativity and problem-solving abilities. An open framework is proposed to bring together the main stakeholders of educational robotics, i.e. teachers, educational researchers and providers of educational robotics, in terms of a common ground based on an activity centered repository. The framework offers different perspectives and approaches such as learning through making to trigger the curiosity and interest of students about science and technology.

Lehman et al. discuss the use of HUBzero, an open software platform operated by Purdue University in US to support scientific collaboration, for the development of STEMEdhub which is a tool for collaboration, research and education in STEM domain [12]. STEMEdhub users can find resources such as lessons plans, simulations and publications in the content repository. Moreover, using search engines they can find the most appropriate content in terms of topic, field domain, grade level or rating scores. The hub supports the concept of groups as the main organizational unit to elaborate on the capabilities of the platform. A group can define a custom template design for unique view of the interface and associate key terms with STEM resources. The use of collaboration tools such as wikis, blogs, forums, calendars, and project management allow groups to build various communities among their members.

The STEM4youth project builds a repository of educational content and teaching scenarios with a goal to make science education and scientific career more attractive to youngsters [5]. Various methodologies and tools such as learning by experiment, demonstrations, social media and games are employed to present the scientific challenges in several disciplines and their impact in everyday life. The STEM4youth approach emphasizes the social dimension and the career prospects associated with the science education by indicating the specific skills that are developed.

IoT platforms like Arduino and Raspberry PI provide tools through their web portals for creating and maintaining their communities. Such tools include forums with topics spanning from hardware and software to education and tutorials, wikis, blogs, newsletter, etc. Project repositories created and documented by the users are also maintained. Furthermore, Arduino Creative Technologies in the Classroom, or CTC [13], is a program focusing on STEM teaching for students of secondary education in collaboration with their teachers. The program provides IoT resources, learning materials and educational services to enable participants to create a more hands-on learning experience in the topics of programming, mechanics and electronics.

The UMI-Sci-Ed platform shares common characteristics and goals with the above approaches and other online portals that collect and present STEM educational material and provide collaboration support to active groups (e.g., Scientix, eTwinning, Micro:bit and Make World). However, it is diversified by integrating under a common technological environment CoPs management and the UMI/IoT technical tools to assist students both acquiring relevant competences and being motivated in pursuing a career in related domains. On the operational level, the integration of the UDOO Neo IoT platform allows to perform remote management of the device, visualize the data, and trigger actions as a result of rules on the received data.

Another differentiation of UMI-Sci-Ed platform is its orientation in instructional design: the educational scenario as a flexible structure has been the basis for designing the platform mechanism for leveraging UMI-Sci-Ed communities. CoPs' members create groups on the basis of designed educational scenarios and further negotiate and experiment on their implementation and splitting in smaller projects in a variety of educational contexts.

## 3 Background Conceptual Models

### 3.1 The Role of Communities of Practice in UMI-Sci-Ed Platform Modeling

Students as future practitioners, need to be able to perform analytic reasoning, interpret information and demonstrate personal and social responsibility. Designing and establishing thus Knowledge Management schemata such as *Communities of Practice* (*CoPs*) in the context of corporate or academic organizations is strongly related to enhancing professional development in the following axes: (a) personal commitment, (b) building trusting relationships with collaboration, (c) opportunities and ongoing support for continuous learning, (d) inquiry based, practice based learning within school settings, (e) respect for differences in practitioners' theoretical backgrounds, prior knowledge, experiences, and expertise, (f) risk taking, and (g) evaluation and feedback [14].

Reflective practice, on the other hand, has significant potential to create educational improvement because it is situation specific and places the professional in the very centre of the attempt to create improvement: this, supported by the use of social networking systems for knowledge management, seems to result in evident advantages such as documenting tacit knowledge and building a sense of community in the context of corporate or academic organizations.

Furthermore, the practice based approach to continuing education aims to create a common ground for individuals and teams to work, jointly reflect, explore alternatives and support each other. A strong assumption in a practice based approach is that CoPs cultivate professional learning and instructional improvement. The framework provided by Wenger et al. on CoPs, defines these as *"groups of people that cohere to through sustained mutual engagement on an indigenous enterprise, and creating a common repertoire"* [15]. The message conveyed by the CoPs theory is that even in apparently routine or unskilled work, there is a large amount of interaction and sense making in completing the task(s) involved.

A knowledge schema as CoPs, needs an identity defined by a *shared domain of interest* and membership implies a commitment to the domain and therefore a shared competence that distinguishes this group from other people. These community members, as they pursue their interest in their domain, engage in joint activities and discussions, build relationships, help each other and share information. The community members as active practitioners deploy practices and use the same tools, working together. Through such interaction they come to hold similar beliefs and value systems: its members are colleagues committed to jointly develop best practices.

In the case of implementing CoPs in the field of education, their perspective affects educational practices along three dimensions: (a) internally, in the sense of organizing educational experiences that ground school learning in practice through participation in communities around subject matters, (b) externally, in the sense of connecting students' experience with actual practice through peripheral forms of participation in broader communities, (c) over the lifetime of students, in the sense of tracing students' learning needs and organizing communities on topics around these.

The model by Wenger et al. [15] in this context is based on social learning; participation is voluntary, membership can be self-selected or assigned, based on the expertise or a passion of the topics. Leadership comes from both formal and informal leaders while organization values innovation and knowledge sharing; knowledge sharing occurs mainly within the community as an emerging and tie bonding process. Under this model the designed and developed learning environment has to incorporate the basic array of CoPs framework tools to achieve, knowledge presentation, communication and collaboration.

In UMI-Sci-Ed approach, the strategic decision has been to design a simple but robust structure supporting CoPs avoiding to a priori structure the educational environment before taking into consideration members' interaction and launching of pilot educational activities. For that reason, knowledge management and collaboration tools are incorporated in the UMI-Sci-Ed platform as will be discussed in the following sections of the chapter. In UMI-Sci-Ed CoPs, a major part is to explore existing processes and then refine those processes through collaboration among UMI-Sci-Ed stakeholders. The collaborative practices that practitioners, as CoPs members, learn to use will enable them to share knowledge and disseminate best practices within their organization and other agencies.

UMI-Sci-Ed CoPs are expected to create, develop and disseminate new tools, systems, and resources based on applications developed via UMI technologies. For creating and supporting the UMI-Sci-Ed CoPs we have selected the model by Snyder & Brigg, as composed by the following phases [16]: (a) discovering the potential,

(b) coalescing, (c) maturity/growth, (d) advocacy/stewadership, and (e) transformation. Each stage has a number of associated goals and activities or tasks. Identifying issues that the CoPs will address, identifying the target population, defining the roles and processes of involving key stakeholders, recruiting participants and identifying key content for CoPs are important actions on following the aforementioned stages.

### 3.2 Instructional Design Considerations and the Role of UMI-Sci-Ed Educational Scenario Template (UMI EST)

The hypothesis examined and explored in this work is that students studying science topics can be empowered by using UMI applications which are developed in the context of model educational scenarios whereas students are provided with meaningful opportunities to participate in the learning process such as in terms of building applications that are relevant to the subject they like. On the described basis vivid interactions take place within student groups accustomed to a practice oriented experience model targeted to provide them with a rich context to grasp scientific knowledge.

Therefore, the pillar of the UMI-Sci-Ed educational learning platform had to be a pedagogical framework, adequately structured, however “open” so as to encourage users’ actual engagement with authentic learning activities regarding STEM and involving state of the art IoT technologies such as UDOO Neo. *Problem oriented project pedagogy (POPP)* is a pedagogical framework that incorporates a series of integrated didactical principles as the basis for the design of this learning environment: problem formulation, enquiry of exemplary problems, participant control, joint projects, interdisciplinary approaches, and action learning [17].

Important issues on applying the POPP are the following: who is formulating the problem to work with, as well as the balance between problem formulation and problem solving. This framework integrates pedagogical principles such as problem-orientation, interdisciplinarity, participant control, exemplary projects, team work and action learning. An important pillar of the educational process is users’ *enquiry on scientific problems* and is the focal center of users’ engagement. In order to understand the problem and find a solution to the problem, users have to go through different stages of systematic investigations: preliminary enquiry, problem formulation, theoretical and methodological considerations, investigations, experimentation and reflection. When users themselves define and formulate the enquiry, they have conscious relation of ownership to it, and they experience the problem fact which encourages involvement and motivation. This enquiry and negotiation between users and experts/mentors sets the learning process in a CoP.

The preliminary phase of problem setting is quite important and has to be supported by materials, lectures, preliminary investigations and review of former work so as users to focus on exemplary and principal problems. *Collaboration in projects* is another design principle embraced by the UMI-Sci-Ed platform’s architecture. In such collaborative learning projects participants have a joint project and a shared enterprise, participants are interdependent, participants own and share the problem, participants have mutual responsibility of learning and collaboration among participants is a long term process.

What consists a design pillar of the UMI-Sci-Ed platform architecture is its focus on the structure and use of educational scenarios. Their formats and use are quite broad, targeted at all levels of typical and vocational education and training. There are limited examples of extending STEM curriculum by employing scenario based e-learning opportunities using state of the art technologies. Educational theories support learning approaches that make learning engaging and meaningful, however the experientalism approach is linked to improving student performance [18].

In this context, to launch orchestrating the learning process the UMI-Sci-Ed Educational Scenario Template (UMI EST) has been designed [19]; the template as the core instructional tool, has been aims to encapsulate all important components of the learning process. In UMI education we need to design "user experiences". Figure 2 shows part of the UMI EST components.

For successful integration of STEM education, there are several characteristics that have to be implemented. The four major features of STEM education include STEM being collaborative, hands–on, problem solving and project-based [20]. Educational scenarios have been used in educational and training practices so as to discuss which futures are preferred or disliked, or pin down the direction of observable trends, or revealing patterns of viewpoints than of a general consensus regarding the future. Different stakeholders develop different - perhaps conflicting-interpretations filtered through their experiences and their own professional and personal values. Since the use of CoPs implies also supporting innovation mechanism through revelation of tacit knowledge, a critical decision has been to incorporate educational scenario structure in shaping the use of the UMI-Sci-Ed platform. Thus, using tools to start constructing a common understanding and springboard for interaction and engagement among different stakeholder groups has been a critical decision and factor of differentiation of UMI-Sci-Ed platform regarding other CoPs' platforms.

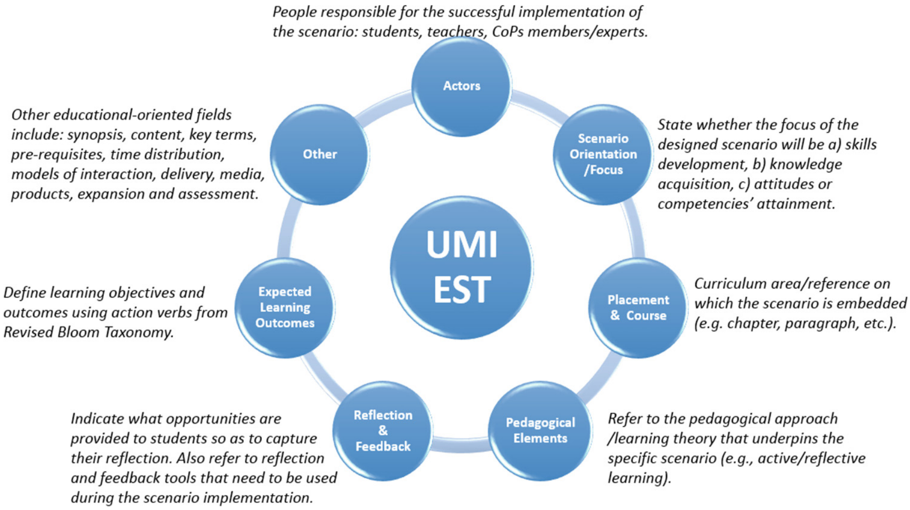


**Fig. 2.** UMI EST representative components.

## 4 Platform Development

### 4.1 Requirements

Social media and Web 2.0 tools have been quite important in forming communities on which users, communicate, collaborate or interact based on digital resources. Given that, systematic attempts in designing and developing web based platforms for supporting CoPs, have emerged in various domains. Typical characteristic of these platforms is the fact that they aim to function as a full-service, digital learning environment, supporting important processes for information sharing, communicating, collaborating on the basis of topics and predefined tasks. These platforms cater for content management services, project coordination services, providing to members feedback mechanisms and the ability to research on already provided content, as well as the ability for members to construct artefacts or digital products on line. These services actually take place in both individual and group level; the working group is the mediator between the individual knowledge as it transforms to community knowledge.

Web supported technological environments for CoPs, by default have to be oriented to uncover the principles embedded in existing learning practices (i.e. a problem of engineering), develop technologies to help students participate in these practices (i.e. a problem of engineering and technology development), and create experimental learning environments designed to develop life skills through participation in a community of practice (i.e. a problem of program design and action research). For these purposes tools for content research and management are important, synchronous and asynchronous communication tools, on line collaboration tools as well as space for presenting co-creation of artefacts or digital products.

Important aspects on the design of UMI-Sci-Ed platform have been the following: (a) relating sensitively to learners and working through agreed processes to build trust and confidence, (b) modeling expertise in practice or through conversation, (c) observing, analyzing and reflecting, (d) providing information, (e) relating guidance to evidence, (f) broker access to a range of opportunities (i.e. discussions with a specialist), (g) providing feedback, (h) target setting and action planning, (i) tailor activities in partnership with the professional learner. It is unlikely however that a self-selected, immediate needs-related form of self-development will produce transformational learning. The provision of online resources, need to be balanced with opportunities for interaction with others who can provide some sort of impetus to inspire a paradigm shift: this could be achieved by supervisors or link tutors working in tandem with mentors and coaches to draw their attention to specific resources which are particularly pertinent to issues arising from practice.

The aforementioned features inform the UMI-Sci-Ed platform development as outlined in the following sections.

### 4.2 Users

The UMI-Sci-Ed platform provides services to support the goals of many different user roles according to the requirements and the background concepts discussed previously. Consolidating all the requirements regarding the users and their roles in the platform, we concluded in the hierarchy depicted in Fig. 3.

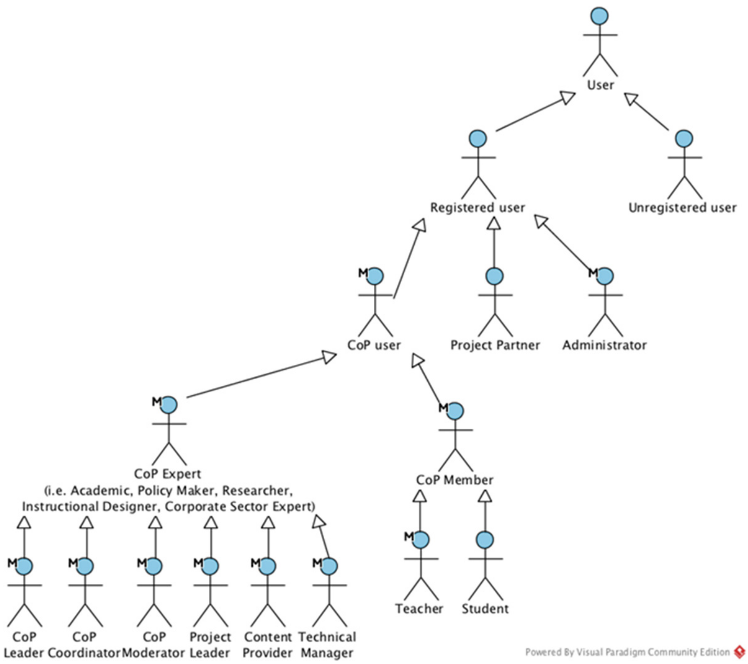


**Fig. 3.** UMI-Sci-Ed platform users' hierarchy.

Table 1 summarizes the goals of the primary users of UMI-Sci-Ed platform.

**Table 1.** User roles and their goals.

| User role | Goals |
|---|---|
| CoP leader | - Identify important issues in the domain<br>- Manage the boundary between community and formal organization<br>- Provide leadership in resolving the problems with and in the practice<br>- Arrange for communication support<br>- Overlook the potential needs of CoPs changes |
| CoP coordinator | - Coordinate information from CoP members to avoid side effects<br>- Inform CoP members about relevant activities elsewhere<br>- Inform others about CoP's activities |
| CoP moderator | - Clarify communications<br>- Ensure that dissenting points of view are heard and understood<br>- Keep discussions on topic and reconcile opposites of view |
| Project leader | - Plan and supervise projects running in CoPs<br>- Monitor members' progress on project completion |
| Content provider | - Design and develop educational material for CoPs<br>- Upload/make public educational material through platform tools |
| CoP member | - Share knowledge and experience<br>- Participate in discussions and other sessions<br>- Raise issues and concerns regarding common needs and requirements<br>- Devise solutions to shortcomings in formally documented methods and procedures |
| Technical manager | - Provide technical support/guidance to CoP members |

The purpose of this analysis is to define the platforms' services that match the requirements of the various CoPs. It should be noted that in practice for CoPs targeting very busy professionals which are overloaded with tasks and information, what is needed is simplicity and flexibility regarding the accessing of the information that will be helpful in their job. For example, finding quickly the current pending tasks for the group someone belongs to or finding the artefacts someone needs to study to be prepared for the next meeting. Such requirements affect the platform presentation layout.

### 4.3 Services

The UMI-Sci-Ed platform offers services that are aligned with the POPP framework and support the goals of the user roles specified in the previous section. The main service categories are outlined in the following.

**Content Management Services.** Content and media sharing are central to the operation of CoPs. Therefore UMI-Sci-Ed platform supports various forms of content management from typical file organization in folders to metadata annotated resource filtering. Given the large amount of data the UMI-Sci-Ed platform needs to handle it is required to provide the proper functionality to organize and navigate such kind of content. In UMI-Sci-Ed the following content management services are supported:

- Management of educational content
- Management of student project specification and results
- Management of UMI app store
- Management of career opportunities/advertising.

For all the above categories of content management metadata editing is a provided feature especially for large document repositories.

Besides content management other collaboration services are evolved around content. Several such services are included in UMI-Sci-Ed platform:

- Collaborative document authoring
- Collaborative UMI app authoring
- Management of discussion forum content
- Management of blogs/microblogs content
- Management of wikis content
- Support social bookmarking
- Import on-line content libraries.

**Project Coordination Services.** Here we have services that implement the project management module that support the creation of a project, allocation of tasks including documents (e.g. the informed consent of the participants) and organizing activities with relevant information. Managing a calendar of events is mandatory so that all CoPs members can be informed of scheduled tasks and find information on previous tasks and meetings. Each user can add a new event to the platform and can visit the calendar section where all events are presented. Access rights can be also defined, i.e. for a new event a user could set the group audience and visibility properties so that the calendar's view can be only seen by members that have access rights.

Evaluation of tasks and project milestones assessment are also provided. Since the participants in a project may create artefacts to solve problems of practice various decision making tools can be used to assist this process (e.g. rank ideas, establish consensus, and systematically analyze information through series of steps).

**Member Feedback and Research Services.** CoPs workings are facilitated by allowing their members to provide feedback in the form of rating a type of content, providing comments, and finding information according to the ratings and access frequency of their colleagues. For a large content repository, like the UMI-Sci-Ed repository, such feedback can be a powerful service to quickly discover the most appropriate content (e.g. a UMI project with specific characteristics and rating) and assist the comprehension on the details of development and usage of such a content.

Poll and survey services are provided to facilitate participation to the workings of a community task from a broader group of users. Different types of questions are supported such as select options, likert-scale, and date and text fields. Analysis of the results is also provided (number of submissions per component value, calculations, and averages).

**Social Media Sites Services.** Although content management systems such as Drupal Commons provide basic services to build social networking capabilities within the UMI-Sci-Ed platform, mainstream social media such as Facebook and Linkedin could also be exploited by CoPs for their collaboration and interaction. As a design decision, a mix of both worlds can bring more benefits where the basic activities are supported by the platform and in addition some discussions and activities are extended into external social networking systems. Some of the mainstream platforms (e.g. Facebook) support programming linkages to their systems through Application Programming Interfaces (APIs) to allow custom integration.

**Supporting Utility Services.** A number of supporting utility services are provided in the UMI-Sci-Ed platform:

*Login:* Allowing user authentication either in the traditional way or login via Web-wide authentication services (e.g. authentication from social networking sites such as Facebook, Twitter, and Linkedin). Existing open standards are used such as OpenID or OAuth.

*Access Rights Setting:* Different roles may have different access rights on the stored content.

*Characterize Content Visibility:* A key feature of this service is a versatile set of access controls that facilitates imposing a variety of privacy policies. The dynamicity of the environment allows for setting access permissions on a fine-grain level allowing a post to be shared to a specific group of users and the next one to be shared with all the participants of a network.

*Notification RECEive:* Notifications are important for the operation of an active CoP. Various forms of notifications are supported such as e-mails, SMSs and social network notifications.

*Web Metric Reports:* Metrics reports provide information about the ways visitors (members and non-members) access, use, and benefit from CoPs content. At the initial stage of evaluating UMI-Sci-Ed platform, it is important to use metrics reports to provide statistics on the number of new members, total number of page views, average number of page views per visit, average number of messages posted per week, total number of messages posted, etc.).

*Submit UMI App to Execution:* Instead of the user downloading a UMI project, this is an advanced feature that is supported by the platform's middleware where the user can submit remotely the application to the h/w platform.

### 4.4 Data

The UMI-Sci-Ed approach generates, uses, circulates and disseminates a big amount of diverse data. These include data that support the educational and training activities, the artefacts and derivatives of the piloting and implementation phases, data that drive the research process that justifies the UMI-Sci-Ed methodology, etc. Both qualitative and quantitative in nature, may either be automatically or manually generated. The origin differs substantially, e.g., data are generated by the participants to the educational activities (e.g., students, tutors, researchers, project members or professionals), researchers that process and analyze the activities and data created in the context of the educational scenarios implementation, sensors or other artefacts producing data in the context of the pilot and implementation phases as well as the UMI-Sci-Ed platform itself. Furthermore, it is clear that the generated data follow different formats and standards due to their diverse nature and post-processing requirements. Almost all types of data are managed through the UMI-Sci-Ed platform in order to support the activities that are realized in the context of various educational scenarios.

Aiming to provide easy access and processing capabilities, all generated data by UMI-Sci-Ed platform have been classified into six dataset categories. This categorisation achieves the provision of a simple structure while keeping the major relevant data collections compact, in terms of the origin of creation and the post-processing that will be applied to the data collections. In specific, the six datasets are:

- DS1: Educational scenarios derivatives. This is the family of datasets that contains all the raw or processed data that are generated during the execution of the pilots as learning artefacts, mainly by the students and the tutors.
- DS2: Research data. This dataset includes all the quantitative and qualitative data (pre- and post-processed questionnaires, reflections, evaluations, etc.) that support educational research.
- DS3: Educational material. This dataset includes all the educational material that is developed by tutors, professionals, domain experts etc.

- DS4: Platform and market analysis data. This dataset includes information about the usage of the platform in the form of log files and evaluation forms as well as overall evaluation data that are used for market analysis and exploitation.
- DS5: Project working data. This dataset includes working documents in the context of the project, such as presentations, draft deliverable documents, deliverable review documents, etc.
- DS6: Other data. This dataset includes other types of information that are gathered in the UMI-Sci-Ed platform that cannot be categorized in one of the above datasets.

Major importance for ethical aspects is data collected as part of DS2 and DS4 datasets. For example in DS2, all data are stored without any reference to the student interacting with the platform and are password protected. In the case of the tutors collecting or generating information (interviews, assessments, reflections, etc.), the information is directly stored to the platform via proper forms with no reference to student personal data. In such cases, only demographic student data are stored (e.g., gender, age) and are password protected. Along the same lines, DS4 data including platform log files are encrypted, statistically processed and aggregated to ensure anonymity.

The UMI-Sci-Ed platform that hosts the above mentioned data has been organized in specific content types that support the educational/training/mentoring etc. activities, the most important being the *UMI Scenario*, *UMI Project*, *Group Article*, *Repository Entry*[1], *Blog*, *Survey*, *Wiki*, *Forum Topic*, *Poll*, and *Event*. In addition, a *Filedepot* is included in the platform that supports information exchange among UMI-Sci-Ed stakeholders. Table 2 provides the platform content types that are used for collecting or exchanging data of the defined datasets.

**Table 2.** Datasets and UMI-Sci-Ed platform content types relation.

| Content Type | DS1 | DS2 | DS3 | DS4 | DS5 | DS6 |
|---|---|---|---|---|---|---|
| UMI scenario | | × | × | × | | |
| UMI project | × | | × | × | | |
| Group article | | × | | × | | × |
| Repository entry | | × | × | × | | |
| Forum topic | × | | × | × | | × |
| Blog | | | | × | | × |
| Survey | × | × | | × | | |
| Poll | × | × | | × | | |
| Wiki | | | × | × | | |

The UMI-Sci-Ed platform is the major place of data collection and presentation either raw or processed data generated by the involved communities of practice. Additionally, publications and related research data are uploaded to Zenodo open

[1] *Repository entry* refers to entries in the Open Repository of the UMI-Sci-Ed platform.

platform (https://zenodo.org/), after proper anonymization, in order to expand visibility. All data of the content types described above that are uploaded in the project platform, including attachments, have a unique and persistent identifier of URI type that is automatically generated by the platform. Research data uploaded to Zenodo also have a unique DOI provided by Zenodo platform.

A first set of metadata has been declared for each of the content types of the platform focusing in educational research while general metadata are also going to be generated. The specific set for each content type has been decided as a compromise between a full descriptive set of metadata for educational research and low requirements of user input, so that to avoid end user dissatisfaction that will prevent users from using the platform. Therefore, *UMI Scenario* and *UMI Project* content types that are basically developed and supported by the project partners and the tutors require a significant set of metadata (provided by user input) during the setup of a scenario or a project. In all other cases user input related to metadata has been minimised.

Following the same principle, attachments in the platform are classified in two major categories: attachments including educational material that supports educational scenarios and activities under the *UMI Scenario* content type and attachments for all other content types. In the former case, educational material is classified in 5 categories, that is, Source Code, URL, Digital Document, Media Object and Rich Text, each one accompanied by a detailed set of metadata that is generated either by user input or automatically by the platform. In the latter case, attachments are categorized as file attachments, image/photos and YouTube videos and are accompanied by a minimum set of metadata that will be generated by user input in order to ease file and media exchange.

The metadata schema for educational research in the framework of the project follows the Learning Resource Metadata Initiative (LRMI) version 1.1 of Dublin Core Metadata Initiative (DCMI)[2], properly adapted and expanded to fulfil the needs of UMI-Sci-Ed. Table 3 provides the properties of *Schema.org/CreativeWork* that were adopted from LRMI specification, new properties introduced, the metadata collection method in the platform and some clarifying comments.

**Table 3.** LRMI properties adopted in UMI-Sci-Ed.

| Property | LRMI | New | Generation method |
|---|---|---|---|
| educationalAlignment | × | | User input |
| educationalUse | × | | Automatically by the platform |
| timeRequired | × | | User input |
| typicalAgeRange | × | | Automatically by the platform |
| interactivityType | × | | User input or automatically by the platform |
| learningResourceType | × | | User input or automatically by the platform |
| artefactType | | × | User input |
| licence | × | | User input |
| educationalRole | × | | User input |

[2] http://dublincore.org/dcx/lrmi-terms/1.1/.

A new set of values has been defined in addition to the recommended by LRMI 1.1 values for the *alignmentType* property. These are used primarily with *UMI Scenario* and secondarily with *UMI Project* content types and are expected to enhance discoverability and reusability of UMI-Sci-Ed data. Table 4 summarizes the use of *AlignmentObject* type and its properties that are used as a basis for detailed metadata in the context of educational research. All metadata are saved in the platform for further use and presentation and they will follow the Schema.org structure.

*UMI Scenario*, *UMI Project*, *Group Article*, *Repository Entry*, *Blog*, *Wiki* and *Forum Topic* content types include a mandatory field for Key Terms or Tags. All of them are mapped to *schema.org/CreativeWork:keywords* property for metadata generation. Therefore, all datasets are accompanied by keywords. Keywords are available as a list (autocomplete feature) while typing new key terms or tags in the above-mentioned content types in order to enhance reusability. Keywords are searchable through the main search function of the platform.

**Table 4.** Properties of Schema.org/Intangible/AlignmentObject used in UMI-Sci-Ed.

| AlignmentType value | LRMI | New |
|---|---|---|
| "learningOutcomes" | | × |
| "educationalLevel" | × | |
| "educationalSubject" | × | |
| "umiDomain" | | × |
| "educationalScenarioOrienation" | | × |
| "pedagogicalTheory" | | × |
| "requires" | × | |
| "activityType" | | × |
| "learningObjectives" | | × |
| "difficulty" | | × |

Versioning of *UMI Scenario*, *UMI Project* and *Wiki* content types is preserved automatically by the platform. Additionally, versioning is available for *UMI Scenario*, *UMI Project* and *Wiki* content types by user input.

### 4.5 Architecture

The goal of the UMI-Sci-Ed platform is to support CoPs through socialization, delivery specific of educational material, entrepreneurship training, showcases, self-evaluation, mentoring, and conceptualization of content and information management. Figure 4 shows the main components of the UMI-Sci-Ed system architecture.

The platform mainly combines a content management system with collaboration tools under a common digital environment and provides a special-purpose middleware for integrating applications with the hardware educational kit for retrieving and visualizing data.

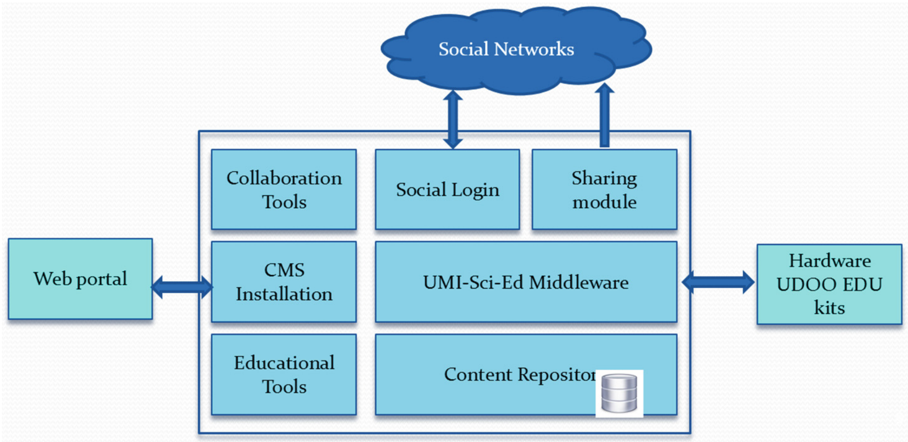


**Fig. 4.** UMI-Sci-Ed platform architecture

The web portal[3] is the front end of the platform and allows stakeholders to access the tools and services of the platform. The portal provides a single-entry point to the digital environment offering a unified user experience to the participants as soon as they familiarize with the environment. Instead of using multiple systems and layouts and keeping track of different streams of information the users are focusing on a single environment. The web portal gives access to services such as content repository access, forum/blog/wiki management, announcements and notifications, user profile area management, commenting and project planning and development.

The educational tools for reinforcing peer learning and mentoring include:

- An open repository of educational material on UMI.
- Self-education, training and evaluation questionnaires and tests.
- A set of training activities that allow the educational community to implement UMI scenarios in real world settings.
- A set of educational scenarios that convey both technological and pedagogical approach to future users.
- A set of UMI projects implementing the educational scenarios.

The content repository includes various forms of content such as educational material, UMI projects and results developed by the students, research results on educational approaches and methodologies, and links to tools for information extraction, management and diffusion of the produced knowledge. A key goal is to provide an "application store" of the UMI projects offering all the necessary information such as: hardware resources for program execution, a library of training materials and other information to support application use.

The collaboration tools enable CoP members to: (a) upload content and publish it to a wide audience, (b) work together in private spaces where they can share documents

[3] https://umi-sci-ed.cti.gr.

and send messages to one another, and (c) ask questions and post responses about project concepts. Other services enable students to work collaboratively on the source code of their projects and share with other CoP members and allow registered users to post ratings (e.g. 5-star) and comments/reviews on uploaded resources so as to produce rankings.

Social login allows user authentication via Web-wide authentication services (e.g. authentication from social networking sites such as Facebook, Twitter, and Linkedin). Here, existing open standards are used such as OpenID or OAuth.

Mainstream social media such as Facebook and Linkedin could also be exploited by CoPs for their collaboration and interaction. In particular, some of the mainstream platforms (e.g. Facebook) support programming linkages to their systems through Application Programming Interfaces (APIs) to allow custom integration within our platform.

The middleware component of the platform supports two kinds of communications: user-to-device and M2M communication. In the first case the middleware supports through a user interface operations such as controlling an IoT device over the web, collecting data from the devices (e.g. temperature), visualizing the collected data and exporting the collected data to various formats. In the second case instead of downloading a UMI project from the repository and installing it on the hardware kit, the user can submit remotely the application to the h/w platform. The communication between the hardware kits and the middleware is based on the HTTP protocol using JSON streams.

### 4.6 Implementation

The core of the platform is based on Drupal 7, an open source CMS with a variety of contributed modules from the community. The current version of the platform has over 90 Drupal modules enabled and properly configured to provide the wanted functionalities. The platform is installed on a web server running Ubuntu Server, Apache 2 as a web server with PHP 7 and MySQL 5 as a database server.

On the user interface, the approach of a user's dashboard is followed where user's information is clearly provided and is associated with relevant content (created by the user, recent used content, etc.). The current version of the platform supports 11 content types (Fig. 5). A user can create a new group, upload a UMI scenario, upload a UMI project, post a new group article, add a new entry to platform's repository, write a new post to a blog, create a survey, write a new wiki page, create a forum topic, create a new poll or create a new event. Users can also create relations between certain content types. For example, a blog post may belong to a specific group, a UMI project may be related to a specific forum topic, calendar event etc.

In particular, the "UMI project" content type allows users to upload to the platform their UMI projects or download projects created by other groups. Each UMI project has a number of specification fields to assist searching and comprehension of the corresponding applications. Fields are emanated from the UMI-Sci-Ed Educational Scenario Template discussed in Sect. 3.2. Figure 6 shows an example UMI scenario definition where a subset of the available fields have been captured.

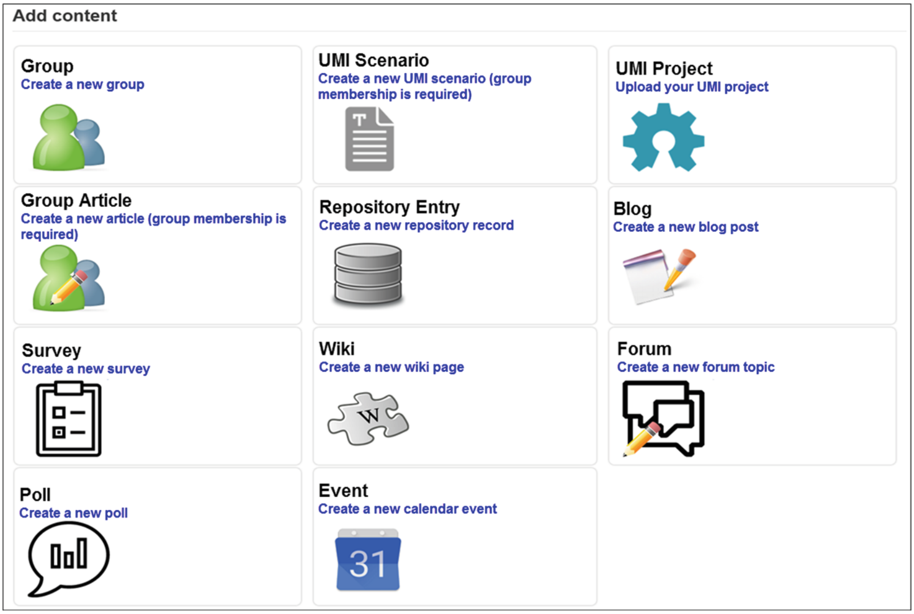


**Fig. 5.** UMI-Sci-Ed portal UI for content management.

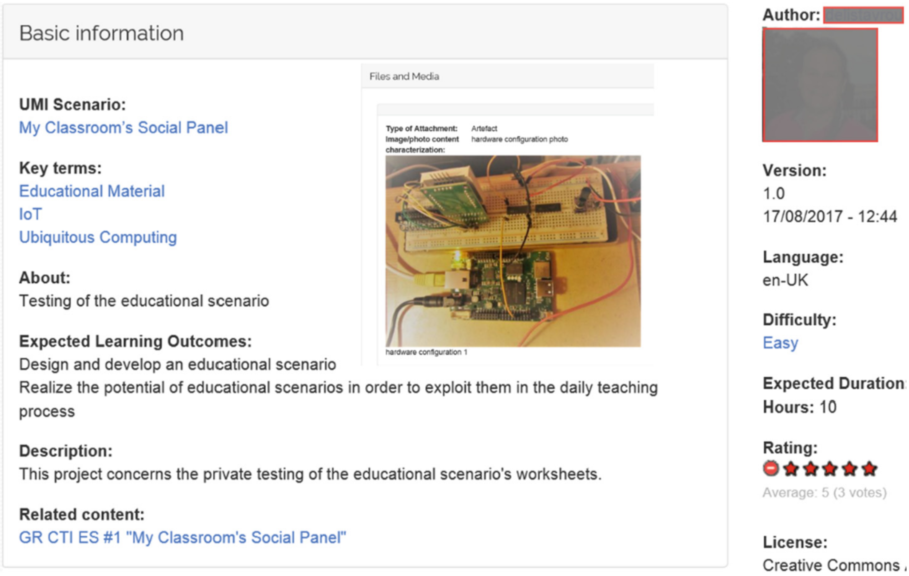


**Fig. 6.** UMI project definition example.

## 5 Evaluation

### 5.1 Example Educational Scenario and UMI Project

The aim of this specific scenario is to explore the Physics laws and the related theory behind the absorption of thermal radiation on surfaces of different colour and material. The students by first configuring and then using the appropriate hardware and software components are able to measure, observe and explain the details of the different behavior of materials regarding thermal radiation absorption.

Its major learning objectives are: (a) to bring about problem solving skills that are connected with UMI technologies and STEM practice, (b) to elaborate on synthesis, analysis, critical thinking and decision making, (c) to provide an insight on how UMI technologies could be used as a means for updating educational practice, and (d) to support students in developing UMI projects through experts' feedback.

One of the experiments designed included the use of a desktop incandescent lamp as a heat source and paperboards placed underneath the lamp (Fig. 7). The distance, position and angle of the material have to be specific according to the instructions and experiment scenario. Under the material a thermistor sensor is placed to monitor its temperature.

From the platform UI students can configure the experiment variables and parameters and give the command to start the measurements. When the lamp is turned on a timer is set typically to 1 min or more depending on the scenario. During the experiment the students are able to observe the temperature graphs displayed depending on the behavior of the material they test each time. So they have the opportunity to make observations, to compare, to reflect or to ask questions and discuss with their teacher.

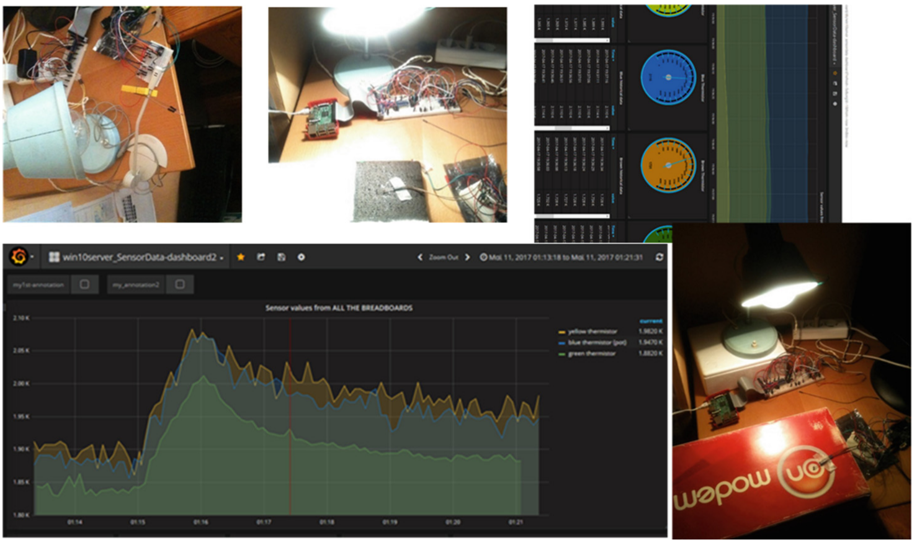


**Fig. 7.** Experimental setup for the educational scenario "thermal radiation absorption" [3].

The open source s/w platforms used to develop the application include:

- Node-red which is an IoT s/w platform that is used to integrate devices, APIs and on-line services with applications. We used this platform to build the user interaction environment of the application, to control devices like the lamp, and to gather values from the sensors in order to store them in the DB.
- The influxDB which implements our database to store the sensor measurements.
- The Grafana, which is the s/w tool used to create diagrams and graphs in order to visualize the sensor measurements.

### 5.2 Preliminary Results

A two days pre-pilot evaluation of the proposed methodology took place in a Greek high school. Fourteen (n = 14) students participated (64% female, 36% male). During the first day students were involved in introductory activities including experimental setup in terms of the required hardware and software components, presentation of material on the course subject, acquaintance with the IoT platform features, testing of the UMI-Sci-Ed platform on-line services and configuration of the UMI applications to be used in the experiments. To collect research data an initial questionnaire has been delivered to participating students, aiming to assess their knowledge on the course topic, their familiarity to technology, as well as to assess attitudes and openness regarding UMI technologies exploitation in education. The students replies showed that: (a) all of them had adequate familiarity with technology; (b) they did not know much about the microprocessor boards and had little knowledge about IoT; and (c) they had a positive attitude and expectation regarding the UMI enhanced educational activity.

During the second day the designed experiments were conducted and the UMI application was used to measure, display and record temperature changes under different conditions and various materials in order to have a hands-on experience regarding thermal radiation absorption mechanisms and make associations with the relevant physics laws.

On the educational part active exploration techniques was possible to apply in line with the principles of reflective and peer learning. For example, the students were asked through worksheets to explore the factors that affect thermal absorption, i.e. distance of material from the heat source, material colour/thickness, position angle, heating duration and amplitude, heat type (radiation, current, conduction, combination), ambient temperature, surface/material temperature etc. They repeated the experiment by changing one factor each time, measured the temperature and compared the results to identify causality or correlations. A playful and participatory approach to increase engagement through gamification was also possible. Given certain task characteristics each team picked the materials that they believed can satisfy the requested properties and behaviour, and validated their hypothesis by using the UMI application. The teams that reached closer to the specifications won.

A second questionnaire was handed to the students with an aim to evaluate both the robustness of the application components and the learning benefits as a result of using IoT technology and applications. The graph at the lower left in Fig. 8 depicts the

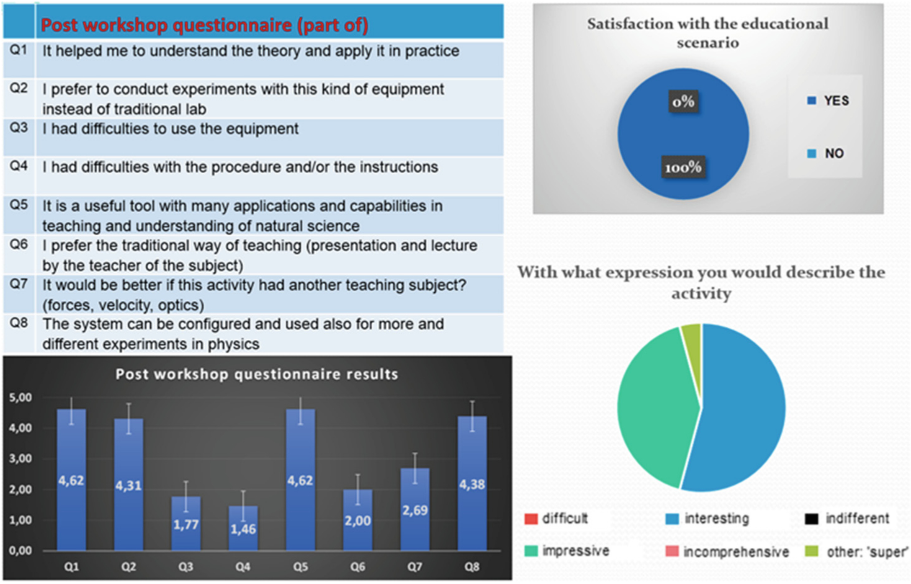


**Fig. 8.** UMI application evaluation results [3].

questionnaire results using a cumulative scoring scale method (Likert scale 1–5). Almost all students conveyed a clear benefit in understanding the theory and its connection to practical use through UMI applications. They also expressed a preference for using the IoT toolkit in combination with configurable software programs compared to traditional analogue instruments and manual recordings. We also surveyed whether the students realized that the approach presented was not representing a monolithic system serving a single purpose but a platform that can be adapted, configured and used in many other Physics experiments. The majority of the students embraced that view which justifies the point that such systems can be accepted as learning tools in school communities.

The overall impression obtained from this first assessment was positive based on the comments expressed by the students. In addition they found the educational scenario to be helpful, the tasks performed useful and rated positively the overall learning experience. The message delivered is that the UMI approach is promising and can be developed to a valuable educational tool empowering students learning experiences. Even with this form of limited evaluation it was possible to test several aspects of the UMI-Sci-Ed platform including the versatility of the IoT toolkit towards supporting the circuit design and implementation of educational scenarios as well as the supporting services of the software platform including delivering of educational material on UMI technologies, sharing of UMI applications, gathering and storing experimental data, supporting polls and surveys and disseminating results and experiences via social media.

## 6 Conclusions

Using scenarios in education enables the orchestration of the learning process as well as the gradual employment of technological tools that further support the learning process as a whole. In our work the structure of the UMI EST has been the pillar and semiotic artefact based on which secondary school teachers, researchers, practitioners, design their own educational scenarios and collaborate on the basis of designing also small projects that actually interrelate with their educational scenarios. The added value of such an inclusion, providing an instructional tool for CoPs' members, so as users to collaborate has been: (a) to create an integrated learning environment with multiple of stimuli for engaging in the design process, (b) to organize design products, emerging out of the design process, and (c) to provide a common basis to all CoPs' stakeholders so as to start building common understanding on communities' purposes, goals and final products. The strength of the scenario approach lies in separating between an intellectual fiction and complex realities as a means to acquire a better understanding of commonalities between "real" organizations (i.e. firms, schools etc.) and an intellectual design.

Although the UMI platform shares common characteristics with other online portals that collect and present STEM educational material and provide collaboration support to active groups it is diversified from them because it integrates under a common technological environment CoPs management and the UMI technical tools to assist students both acquiring relevant competences and being motivated in pursuing a career in related domains. On a technical level, the middleware layer of the platform allows to perform remote management of the IoT device, visualize the data, and trigger actions as a result of rules on the received data. Another differential aspect is the use of the designed Educational Scenario Template as the core instructional tool, to encapsulate all important components of the learning process.

The evaluation presented represents a set of preparatory activities required for the official UMI-Sci-Ed pilot studies setup. Field research will follow in educational conditions involving five European countries (Finland, Greece, Ireland, Italy and Norway) in order to test in a broad educational context the UMI-Sci-Ed methodology. The research sample includes five schools from each country and about 25 students per class.

The participation of the students, the teachers and the school community members is expected to produce several outputs. Variables to be analyzed include usability, motivation interest, knowledge and engagement. Media include surveys, interviews, observations and cognitive tests. The collected quantitative and qualitative feedback elements are going to be analyzed to construct knowledge about the whole process. The results of using an evaluation framework that will assess the impact of such activities in terms of learning gains are also expected.

**Acknowledgements.** The UMI-Sci-Ed project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 710583. The authors would like to thank the fellow researchers who participated in this project.

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