Journal of Universal Computer Science, vol. 25, no. 12 (2019), 1554-1588
submitted: 25/4/19, accepted: 31/10/19, appeared: 1/12/19 © *J.UCS*

STEM Oriented Online Platforms Embracing the Community of Practice Model: A Comparative Study and Design Guidelines

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Abstract: Science, Technology, Engineering and Mathematics (STEM) education is a strong case of a multidisciplinary teaching and learning process, apt for transforming the conventional instructor based courses into ones, where the syllabus focus is on problem solving and discovering exploratory learning. In this context the adoption of the Community of Practice (CoP) model can enhance the learning process. Although existing web portals provide STEM educational material and teamwork tools to active members they fall short to support state of the art trends in science education. To advance STEM education a fusion of diverse tools like learning management systems, computer-supported collaborative learning, online CoP management and contemporary technological platforms (e.g. Internet of Things, mobile and pervasive computing technologies) is advocated. This paper first identifies the common features required to build CoP enabled online platforms to support STEM education and classifies them in seven axes to form an evaluation framework for this domain. A comparative analysis of fifteen (15) STEM oriented web based platforms is conducted, based on features of the defined evaluation scheme. A critical presentation of their design characteristics is highlighted by exploring tools and services on the technology viewpoint and underpinning learning theories on the education viewpoint. Important findings presented in this paper form a generic framework of design guidelines for building STEM oriented online platforms that embrace the CoP model.

Keywords: STEM education, Community of Practice (CoP), Internet of Things (IoT), comparative analysis, design guidelines, web based platforms
Categories: L.3.0, L.3.5, L.3.6

1 Introduction

Modern societies invest in research and technology oriented educational programmes to extend their ability of addressing current and future global-scale challenges, such as climate change, energy supply, healthy aging and digitalization [Eilks, 2015]. Skill-biased technical change [Acemoglu, 2011] refers to the idea that technological developments have driven up the demand for skill labor. In this context the approach which has been closely interrelated with future job opportunities is the *Science, Technology, Engineering and Mathematics* (*STEM*) education [Xue, 2015]. In the European Union, for example, there is a strong interest in STEM skills and there are projections for 8 million STEM job vacancies in the next ten years [Brzozowy, 2017].

Contemporary pedagogical approaches to STEM education advocate for learning that emerges from vivid interactions within student groups in a way that practical experiences provide an attentive context to grasp abstract science [Martinez, 2013]. This is a bottom-up learning approach following a constructionist way instead of instructionism in the sense of actively experimenting and producing new knowledge [Toh, 2016]. STEM education focuses on developing a range of key skills that are essential for living and working in today's world as learners engage in activities that include: a) using their skills and content knowledge to creatively solve problems; b) imagining, questioning and exploring; c) collaborating with others; d) engaging in inquiry and analysis; e) innovating, designing and making; and f) testing and modifying their solutions to complex problems. As new learning paradigms emerge, the use of state of the art technologies such as Ubiquitous Computing, Mobile Computing and Internet of Things (UMI) technologies can open new opportunities for STEM education [Goumopoulos, 2017], [Goumopoulos, 2018], [Fragou, 2017] as they are built on STEM interdisciplinary principles which actually reflect a deeper understanding of science concepts, integrating physical and technological space, devices and human networks.

In line with the goals of STEM education, knowledge management practices such as the extended use of professional networks, *Communities of Practice* (*CoPs*) and *Communities of Interest* (*CoIs*) [Wenger, 2002], [Archibald, 2008] can be applied to support emerging learning where the knowledge is constructed by interactions and communications between the relevant stakeholders. CoPs, in particular, have been broadly projected as strategies to capture tacit knowledge [APQC, 2001] by using state of the art technologies and relevant supporting tools. CoPs as informal groups improvise solution to problems and immediate mutual understanding, promoting thus a collective use of knowledge for educational or professional purposes.

Although existing web portals provide STEM educational material and teamwork tools to active members they fall short to support state of the art trends in science education. To advance STEM education a fusion of diverse tools like learning management systems, computer-supported collaborative learning, online CoP management and contemporary technological platforms is required.

Given the importance of STEM education and the pivotal role of CoPs to attain educational goals the research questions explored in this paper have been the following:

RQ1. Which are the characteristics/properties of an online CoP based platform supporting STEM education?

RQ2. How current STEM oriented online platforms respond to these properties and compare to each other?

RQ3. Which are the design guidelines for a fully CoP based online platform in the STEM domain?

This paper, aims to explore and address commonalities and points of differentiation regarding the design characteristics and services in existing online STEM platforms based on the CoPs theory. Its purpose is to offer domain experts, educational practitioners and CoPs' stakeholders some practical guidance based on evaluation prior to adoption in educational or corporate practice. The educational and technological dimensions have been set as important pillars for defining seven feature categories, which serve as an evaluation framework, so as to explore and evaluate services in fifteen relevant platforms. The comparative study conducted aims to provide, guidelines to engineers, educational practitioners and developers for the future design of STEM online platforms as rich learning environments which encapsulate the social interaction dimension of learning through communities' use.

The remaining of the paper is organized as follows. Section 2 provides an overview of Web based platforms characteristics for STEM education, presenting also important features and design characteristics of CoPs as a knowledge management strategy. This section also gives insights on what STEM online platforms would be like with the CoP model and without the CoP model by describing design features and characteristics. The rationale and procedure for selecting the evaluation axes for STEM oriented platforms embracing the CoP model are also provided (response to RQ1). Section 3 describes the methodology applied for the evaluation of the online STEM platforms. The data collection for subsequent analysis is discussed (response to RQ2). Section 4 provides important insights on the results presented emphasizing on a set of design guidelines for the development of online CoP based platforms supporting STEM education (response to RQ3). Section 5 concludes the paper and proposes future research.

2 Background

2.1 Web Based Platforms and STEM Education

Digital technologies seem to transform the potentials of STEM learning since they foster sensori-motor experiences and interaction with the environment as well as providing the digital space for students' exploration of abstract ideas and invisible phenomena. There is a broad array of web based platforms that is STEM oriented, the majority of them focusing on the free access of learning resources or the provision of instructional tools for STEM teachers. In effort to summarise the criteria for developing web based platforms for STEM education, they seem to vary regarding their: a) design rationale; b) operational characteristics; c) development methodologies; and d) end-users (i.e. education vs. company sector) [Sun, 2008], [Ardichvili, 2003]. The current use of these platforms implies dependencies on their target groups, their link (or not) with curriculum and education, and their link (or not) with market orientation and trends and the implications this brings for organization stakeholders (and perhaps policy makers) [Mueller, 2009]. As a consequence, there is pluralism both in the design and development mechanism of these learning environments and in the level of their responding both to users' needs and to embracing pedagogical trends in modern education [Koubek, 2002].

For example, there are platforms that simply use repositories linked with groupware, such as forums and there are platforms that use a great variety of tools and services, which are oriented towards specific pedagogical goals such as supporting independent learning, constructionism etc. The number of tools and services used on shaping the educational learning environment as well as the way they are utilized to support users' needs actually shape the added educational value of these online platforms as *Virtual Learning Environments* (*VLEs*) [Graf, 2005], [Carnevale, 2011] The most elaborated versions of these platforms offer administrative tools (such as tracking students' performance) and management tools, providing opportunities for authentic learning, simulating work based environments and cultivating soft skills and higher order thinking development as well as online collaboration mediated through educational models. Such services can also support the development of technology based constructions and products such as artifacts, mock ups, code writing etc.

Web based platforms, embedding digital tools such as simulations and modelling environments form a more integrative approach in teaching and learning for education and vocational training as well as STEM disciplines [Dube, 2005]: they orchestrate a plethora of tools, they produce various sets of data and they use multiple technological stimuli to provide an integrated technology mediated learning environment. In this context, open access activities that are designed to cultivate intentional play are also important in the sense that they offer low barriers to entry STEM based learning and encourage creative expression of ideas, while still engaging diverse students in complex and difficult content. At present, indispensable management services of online platforms are the following [Hoidn, 2014], [OECD, 2014], [Bonsworth, 2013], [Borbonada, 2012]: services for including and updating user profile; services for creating courses and cataloguing them; services for creating tests described through a standard; user tracking services; services for managing reports on content/tools frequency and use; services for creating, organizing and managing own training contents or contents provided by other producers.

According to STEM 2026 vision a major component in effectively achieving and disseminating STEM learning is the formation of engaged and networked CoPs [STEM, 2016]. Though VLEs could -from a technical perspective- be used to shape this kind of communities, their formation is not so simple. An active CoP in STEM does not entail only a predefined personal and collaborative space, supported by a repository of resources. Especially it entails the simultaneous interaction of various stakeholders for learning purposes, achieving collective learning through a shared mission, regular interaction and building relationships through jointly implemented activities. The majority of the web based platforms for STEM education are not oriented towards working processes and contexts, though they appear to provide free access to digital tools or instructional design tools for STEM education. Even the existence of collaborative spaces (e.g. forum, chat) in integrated learning environments such as the VLEs does not mean automatically that collaborative learning takes place. The activities of STEM education in these environments is important to be work based, members to use collective problem solving strategies and actions so as to construct in, active time, new products, new knowledge, using or simulating project management processes in working conditions [Levy, 2010]. Translated in the STEM context, this acknowledgement means designing educational experiences that include interdisciplinary approaches to solving "grand challenges" but also involve students' interaction with innovative modes of learning (e.g. flipped classroom) and innovative technologies (e.g. Intelligent Tutoring Systems, Augmented and Virtual Reality). The inclusion of all society members, who vary in technological and professional background and supporting established, active, collaboration between different groups of stakeholders (e.g. game developers and learning scientists) also appear as important goals of a well developed web based STEM oriented and CoPs supporting platform [Volpe, 2005].

2.2 The CoP Model

CoPs as a powerful Knowledge Management schema are based on the new model proposed by Lave and Wenger [Lave, 1991] as situated learning; this model is based on informality through social interaction, resulting in authentic, motivated learning of what is needed to be known. This model promotes the constructivism and situativism characteristics of learning. The emphasis is on learning (not in teaching), taking place in situ, by observation (therefore socially), and informally as it has been driven by a task, not in a sense of strict curriculum planning. Learning in this case is about understanding how to behave, what to do, whereas in the same time this realization brings as a result a member's identity change. This model however, does not imply that a CoP is a unified, neatly bounded group; a CoP is never defined precisely and it is not a "primordial culture sharing entity" [Lave, 1991, p42]: members involved have different interests, viewpoints, backgrounds however they come together as they participate in an activity system in which they share understandings on what they do, they exchange narrations, practices, tools that expand their skills and expertise in a specific topic. Under this context, the term of community does not necessitate co-presence but it involves the use of informal groups to improvise solutions to problems, bringing forward "improvised new practice" in the sense of non canonical knowledge.

CoPs involve specific features but also a process. Various stakeholders (domain experts, users, CEOs etc.) are members of the community, the community has a flux structure (periphery and core members), relationships are based on interaction and learning together. As important features the domain, the practice and the community shape the core of the CoP. Important domain concepts, tasks and practices involved, exchange of narration, digital artifacts and relationships as shaped by the members' interaction come together in the context of organizations in the scope of connected people and tools. As structures the CoPs bring forward the transfer problem, when for example individual learners may appear to know something (for instance a skill for solving a math problem) but they fail to apply that knowledge in a context different from the one in which they learned the skill. The process based definition of CoPs involves the description of the process of knowledge generation, application and reproduction as learners enter a community and gradually take up its practices through legitimate peripheral participation. In a sense, over time members take up more and more of the identity of group membership and centrality and more and more of the central practices of the group. Active participation and learning in the community involves the existence of experts and members' enculturation in the CoP presupposes that the community already exists, with some sort of history and identity.

The idea of a CoP differentiates itself from other knowledge communities as it describes the natural occurring processes underlying all knowledge and learning. The formation of CoPs is not an endemic phenomenon that occurs naturally by a teacher, a chief information officer, a community organizer or an organisation and does not involve only external representations and explicit rules, i.e. technology platforms which instantiate a particular way of supporting or fostering a CoP. It is important to involve and implement influential strategies but also distinguishing between the pedagogical theory underpinning it and the design. In STEM (and other disciplines) knowledge building communities are popular examples of implementing social learning theory; however, often in literature the terms knowledge building community and CoPs are used interchangeably, or occasionally with one as special case of the other [Hoadley, 2005].

Knowledge building communities which are based on the use of collaborative tools and digital spaces in STEM education are discussed as a framework for understanding social learning environments. However, between the terms knowledge building communities and CoPs there are key differences. Most notably, a knowledge building community is intentional, whereas CoPs have to be formed unintentional, oriented towards a different goal, which is to complete professional tasks and members be comfortable within their professional identity. The source and nature of authenticity is also a difference between CoPs formation and existing knowledge building communities. For example, in knowledge building communities members can investigate questions that may arise from a learner's curiosity or specific teaching agenda. However, a CoP does not typically have a predefined learning goal but the latter is going to emerge depending from the community's evolution, function and role in society.

Varying terminology regarding the use of communities for learning purposes exists such as "community of learners", "knowledge networks", and "communities of interest", all of these highlighting different dimensions [Andriessen, 2005]. However, according to [Andriessen, 2005], there are two dimensions of variability among knowledge communities: "connectivity" and "institutionalization". While connectivity refers to the degree of social connectedness of the members, relying primarily on identity and the degree of interaction, institutionalisation refers to contract value (i.e. deliverables), shared purpose, defined membership, composition and formalization. The acknowledgement of these variables implies the production of various clusters. For example, moderate connectivity but low institutionalization characterizes "informal networks", whereas high connectivity and high institutionalisation characterizes CoPs and "strategic communities". Even with that categorization, clearly one of the biggest differences between knowledge building communities and CoPs is "the degree to which the core practice or value of the community is a learning practice as opposed to some other authentic professional or lively hood related practices" [Andriessen, 2005].

2.3 Developing CoPs in STEM Learning Environments

The practice of STEM disciplines can inspire a passion in students for research and exploration and cultivate skills such as teamwork, stamina, and the application of acquired knowledge to new situations [Bailey, 2015], [Brzozowy, 2017]. Integrating in STEM oriented platforms knowledge management schemata such as designed and networked CoPs, provides consistent exposure to respective STEM epistemology and computational thinking through the support of teachers, school and educational program leaders, corporate and academic sector stakeholders but also school- and community-based role models. These formal and informal educators seem to harness one of our greatest assets in transforming STEM education—*learners' curiosity.* Intentional play activities can support a process of curiosity and inquiry, joyful, hands on experience, trial and error learning by giving students the time to explore their doubts, build experiential knowledge, and reinforce relationships [Brzozowy, 2017]. In this context, online CoPs based platform technology provides to students opportunities to construct and understand models, engage in collaborative projects by using data collection and analysis techniques, experience decision making scenarios but also use virtual learning interfaces that keep them engaged on tasks, becoming self-motivated, than externally driven [Cuddabah, 2011], [Koliba, 2009].

In the case of STEM web based platforms which integrate the CoP model the educational material and processes involved are very important. Orientating students towards learning pathways and STEM role models is critical in members' acquiring the STEM culture. Students' dealing with important real world problems ("grand challenges") puts an emphasis on the process of conceiving and developing solutions through interdisciplinary work. Learning bootstrapping methods (the ability to make sense and resolve complex situations using existing resources and knowledge) entails students being tasked with complex and difficult challenges, often where one right answer is not yet known or expected. Incorporating also interdisciplinary teaching and learning approaches that appropriately and effectively show connections among key concepts and ideas between two or more STEM disciplines or between one or more disciplines and a non STEM discipline seem more effective than simply integrating content across traditional, siloed based, classes.

Wenger has proposed seven functionalities for IT supporting CoPs including home page, conversational space, directory of members and shared workspace, a search engine to retrieve resources and community management tools [Wenger, 2009]. STEM web based platforms comprising the technological research sample in this work, do not make actual use of all the seven functionalities as proposed by Wenger. STEM platform development from a design perspective is summoned to adhere to specific needs and strategies implemented to shape these CoPs, for instance start with a simple facility or deploy a community oriented system etc. A fully developed STEM oriented platform supporting CoPs is important to address shaping of the domain knowledge of the CoP, collaboration and sharing content with other users, coordination (e.g. Calendar use), stimulation and debating. The benefits and the impacts of establishing and maintaining CoPs could be summarized as follows [Kimbleet, 2008], [Lai, 2013], [Murillo, 2008]: a) providing access to new knowledge used to enhance organization management; b) fostering trust and a sense of common purpose; c) generating knowledge and encouraging skills development; d) disseminating valuable information and transfer best practice; e) initiating new lines of business including new products and services; f) decreasing the learning curve for new practitioners or employees; and g) helping recruit and retain talent. Important techniques for supporting CoPs through technology imply linking people with other who have similar practices, or providing some sort of shared repository of information resources, supporting communication with discussion tools and providing awareness in a community of the information context of various resources. However, not all of the selected web based STEM oriented platforms make full use of these techniques as they appear to differentiate in the specific needs and strategy they use.

Platforms dedicated to CoPs are important to combine features of user oriented platforms (mainly platforms based on Web 2.0 technology) and application oriented platforms (such as iGoogle with widget holders). A typical characteristic of STEM web based platforms which fully support the CoP model, is the fact that they aim to function as a full-service, digital learning environment, supporting important processes for simultaneous information sharing and data processing, communicating, collaborating on the basis of topics and predefined tasks [Yoon, 2007], [Kimble, 2008]. Those platforms cater for content management and 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 artifacts or digital products online using coaching and mentoring processes. The existence of roles in the community, and valid rules for communication and users' interaction, shape community's organization, whereas participants' profiling and personalization –when possible- of content, or impact evaluation of the deployed services of the community, and the common language among users appear to be core characteristics in structuring a STEM oriented web based platform supporting CoPs.

STEM oriented platforms fully incorporating the CoP model as proposed by Wenger is important to make full use of the three areas of technology affordance relevant to CoPs including, content, process and context [Hoadley, 2005]. This entails the ability to store and manipulate information in a variety of formats, scaffold a particular task, activity or sequence of actions and enable through technology to shift the social context of the user. On the basis of the previously stated considerations, the parameters of interest regarding the actual STEM and CoPs' oriented platform design and the services provided, could be divided into four macro fields: a) system requisites; b) training resources and course management; c) user management; and d) services offered to users [Murillo, 2008], [Yoon, 2007].

The existing platforms supporting STEM education appear to differentiate on the basis of these macro fields according to the level they support CoPs schemata, and to the level they adhere to a basic CoP model structured upon the important components of Domain, Community and Practice [Lave, 2002]. Basic services and tools (e.g. chatrooms, repositories etc.) are incorporated by the majority of platforms, whereas others make use of further advanced technology (e.g. online labs). Developing the structure of the community entails additional requirements such as representation of content and its management, visibility of information (i.e. using data visualization tools) and social orchestration of activities. Platform services such as management of enrolments, training paths, and student tracking are really significant and convey an added value in modern education [Dube, 2006], [Resnick., 2000], [Coliba, 2009], and are closely interrelated with CoPs' formation essence. As a consequence, such systems are ahead of others in service provision, as these tools will represent in the near future the core of e-learning environments.

A set of generic design features of a web supported CoPs involves a content repository, discussion forum functionality, features such as chat, news, e-newsletters, web conferencing, learning tools and modules, search functionality, membership (open or closed), moderator capabilities for forum and content submissions [Stanoevska, 2001]. However, the most pedagogically advanced web based platforms arguably are characterized by the encapsulation of constructivist principles such as the following: a) learning takes place in authentic and real world environments; b) learning involves social negotiation and mediation; c) content and skills are relevant to the user; d) content and skills are understood within the framework of the user's prior knowledge; e) users are encouraged to become self-regulatory, self-mediated and self-aware; f) experts function as coaches and mentors, and they encourage multiple perspectives and representations of content [Zhang, 2008)]. The interdisciplinary character of these communities is important in the sense that they have to integrate a plethora of professionals and users with a different background [Delaney, 2017].

Content, communication, collaboration and interaction are important concepts on which the design rationale of CoPs is built [Wenger, 2002]. The model of CoP is also strongly linked to creating professional identity and for that reasons personal space, stimulating motivation and acknowledging active members is quite an important dimension in respective STEM oriented platforms. As a conclusion, fundamental services offered by CoPs' platforms are: a) knowledge services supporting sharing of information and knowledge as a prerequisite for communication; b) intention services supporting signaling of intentions as a prerequisite for cooperation, c) negotiation and contracting services supporting negotiation of mutual obligations as part of coordination, and d) services for the settlement of obligations (i.e. performance of tasks) [Barnett, 2012], [Klamma, 2004]. Since delivering training services remains a characteristic and valuable feature for building a CoP supported platform in the STEM domain as a fully integrated learning environment, massive – but also safe - access to educational content, planning of online activities and strong authentication services shape the infrastructure for achieving that.

2.4 Evaluation Axes and Features (RQ1)

2.4.1 Selection of Evaluation Axes

The prevailing guidelines in literature pertain to the economic, social and managerial aspects of the community development [Mynatt, 1997] and appear to neglect the technical aspect [Wenger, 2001]; however, identifying components of STEM oriented platforms embracing the CoP model and pinpointing guidelines for technically implementing IT tools to fully support CoPs is a factor which is equally important for effective community building. In order to define the evaluation axes for the STEM oriented platforms which to a major or less extent embrace the CoPs' model structure [Yoon, 2007], we have conducted the following process: a) critically examined and analysed the respective CoPs and STEM literature; b) conducted a needs analysis based on ethnographic practices (interview) involving domain experts so as to define core characteristics of web based CoPs' platforms oriented to STEM; and c) taken into consideration Britain and Liber's components [Britain, 2006] so as to represent properties that should exist in web based STEM oriented CoPs' platforms. The evaluation axes presented in this paper are based on the design principles of the UMI-Sci-Ed platform [Goumopoulos, 2018], proposed in a blue print and comprised after the domain experts' validation of the UMI-Sci-Ed platform architecture.

Launching and sustaining successful CoPs requires the implementation of a thoughtful strategy that considers the communities' goals, incentives, roles, content and other non technological criteria. As there are dozens of collaboration platforms and tools [Dube, 2006], each with different permutation of features, choosing the appropriate configuration proved a highly demanding process. As the technology component could take on a life of its own and miss the big picture we have acknowledged as important to engage in careful planning. To avoid pitfalls endemic to online community projects, we have tried not to lose sight of overall goals of the initiative (to launch and sustain fully CoPs) and support modes for creating value and connections of participants. Though there is a variety of approaches in designing web based CoPs [Barett, 2004] which differentiate in respect with the community goals and audience needs addressed as well as audience scenarios and functional requirements [Hoidn, 2014] we aimed at selecting criteria which correspond to Wenger's theory on technology support of CoPs. Wenger, White and Smith [Wenger, 2009] have developed a list of common orientations that CoPs can have such as meeting support, project infrastructure, content collection and organisation, access to expertise and context serving. For that reason we have identified specific and analytical axes, incorporating a variety of formats and digital affordances so as to describe rich functionalities in community management (e.g. content management functionalities, member interaction tools etc.) in an effort to fully "translate" the CoPs' model in technological affordances for STEM oriented web based platforms supporting CoPs. The platform features qualified in this paper are related to: a) content presentation and management; b) roles and levels of interaction among users; c) formats on presenting material; d) motivation and incentive of CoPs' members; e) project management mechanisms so as to enhance collaboration; f) pedagogical tools; and g) supportive services and tools used. Based on the above, we have defined the following categories/axes which have been used for the comparative evaluation of the selected online STEM platforms Figure 1.

The *Content* category refers to content creation, editing/processing and presentation/visualization services provided in the STEM oriented platforms; this axis relates to the digital tools used for administering educational content in multiple ways (e.g. file repositories, blog, microblog, wikis, social bookmarking etc.). The *Member Interaction* axis refers to synchronous and asynchronous ways of interaction within a community including social networking, member commenting and feedback, discussions, webinar facilities and research services (e.g. polls and surveys) discussions, provision of feedback in the form of rating a content type or providing comments, and finding information according to the ratings and access frequency of members. The *Project Coordination* axis refers to coordination of different tasks, informing members about upcoming events, managing the workload and collective decision making, referring to time planning, task planning as well as to decision making tools. The *Incentive and Recognition* axis refers to the practical use of incentives so as to encourage participants to learn through a variety of rewards such as badges, rewards or reputation management systems which are related to building connections among community members by working on shared values and views. The *Social Media and Communities* axis refers to the exploitation of mainstream social networks such as Facebook, Instagram, Twitter, and LinkedIn in order to promote the platform objectives. The *Supporting Utilities* category refers to auxiliary services such as user authentication, content access criteria and notifications. The *Supplementary Topics* category relates to features enhancing learning practices such as explicit integration of contemporary technologies (e.g. Internet of Things, mobile and pervasive computing technologies), technology framing by pedagogical principles and the provision of application programming interfaces (APIs).

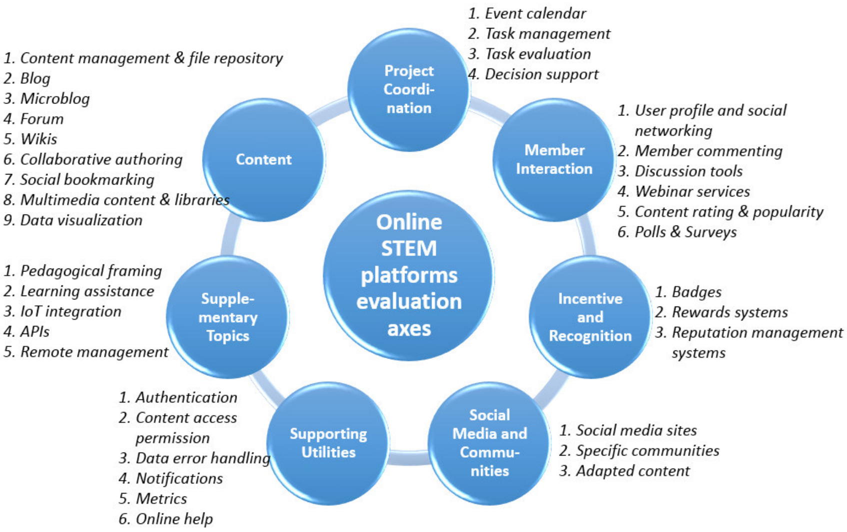

Figure 1: Evaluation axes for STEM oriented platforms embracing the CoP model

2.4.2 Validation of Evaluation Axes

Evidence on the validation of axes appropriateness was inquired by using our experience from the design and development of UMI-Sci-Ed platform; the development process has made use of the evaluation axes' features presented and defined in this paper, by taking also into consideration important principles and guidelines of community oriented design [Stanoevska, 2001], in the context of components and services such as the Community definition, Implementation processes and Transaction and Infrastructure view [Stanoevska, 2000].

Furthermore, to validate the evaluation axes discussed in this paper we have used feedback from domain experts and school practitioners in STEM domain who have used in their practice the UMI-Sci-Ed platform, collecting qualitative data in an online validation form. The participants used a short questionnaire form with a total of fourteen (14) items, seven (7) of them, closed type, with a 5-scale rating range (Very Important to Not at all Important) and seven (7) of them with respective questions covering the seven categories of the evaluation scheme in an open ended format. Even though the version of the UMI-Sci-Ed platform used was not supporting operationally all the features of the evaluations axes, the participants acknowledged the appropriateness of all the categories to fully support CoPs in STEM domain. Table 1 summarizes the results of the participants' feedback (8 domain experts and school teachers that have used the UMI-Sci-Ed platform) on the evaluation axes and added pedagogical value of digital tools used as perceived and experienced by them.

Evaluation Axes	Significance	Result	Added value in CoPs
Content Presentation & Management Tools	Very Important Important	87.5% 12.5%	Better presentation of CoPs' content; Easy access and comprehension of CoPs' goals; Students' motivation through direct access of educational content.
Member Interaction Tools	Very Important Important	62.5% 37.5%	Support of decision making and filtering of new ideas; Effective project management of students' groups; Supporting the STEM related nature of CoPs.
Project Coordination Tools	Very Important Important	75% 25%	Facilitate member communication; Increase student engagement through voting, polls etc
Incentive & Recognition Tools	Very Important Important Not Applicable Less Important	37.5% 25% 12.5% 25%	Badges reinforce students' interaction; Enforce motivation through psychological mechanisms.
Social Media & Communities Tools	Very Important Important Not Applicable Less Important	12.5% 50% 25% 12.5%	Tracing CoPs' members common backgrounds and interests; Disseminate the scientific justification of CoPs' work; Expanding students' skills in social media.
Supporting Utilities	Very Important Important	75% 25%	CoPs' data management; Good platform performance; Important platform architecture services.
Supplementary Topics	Very Important Important Not Applicable	12.5% 25% 62.5%	Access to remote learning resources; Advanced support of platforms' mechanisms in group work; Remote management of experiments.

Table 1: Feedback from experts and school practitioners in STEM domain

3 Comparative Study on Online Platforms Supporting STEM Education (RQ2)

3.1 Methodology

The comparative study's aim, presented in this paper has been to explore the field of STEM oriented, web based platforms that could support online CoP management for educational purposes by assessing the provision of features categorized in the seven axes discussed in Section 2.4. Since the research questions addressed cumulative knowledge (i.e. guidelines) and important components for fully developing web based STEM oriented CoPs, in our research design, we have supplementary used both the exploratory and descriptive approach: *exploratory*, so as to trace commonalities and differences among STEM oriented platforms and the degree up to which these support the CoP model, and *descriptive*, in an attempt to identify important features that according to the collected data appear to be missing from CoP based platforms [Galliers, 1992], [Lave, 2002]. Such findings could be important for STEM stakeholders interested in STEM education through online CoPs since they provide the ground for further development of the respective technology.

The methodology procedure, as a follow up from the relevant research survey, comprised of the following steps: a) tracing the web based platforms for STEM through specific web technologies; b) recording requirements and characteristics of STEM oriented online platforms supporting CoPs; c) grouping the characteristics of STEM oriented platforms supporting CoPs for matching the seven (7) evaluation axes defined in Section 2.4; and d) conducting evaluation based on actual trial and testing of the platforms' services. To support the survey intake we have used as supplementary material relevant documents (e.g. platforms' manuals and guides).

Conducting an analytical and comprehensive literature review towards STEM oriented platforms, their provided services and digital tools in the context of online CoPs characteristics has been the basis of our methodology. The review included studies which directly dealt with web based platforms' characteristics and services as retrieved from relevant literature and research papers. In order to capture a quite representative corpus of papers we have conducted search in major databases such as Google Scholar and ScienceDirect by using keywords which do not only address major aspects of learning processes of online communities but also the state of the art technology involved , as partly retrieved from the STEM 2026 vision. Keywords that were used include: *Education, Communities of Practice, Online platform, Internet of Things, Social media, STEM, projects, tools, u-(ubiquitous)Learning, m-(mobile)Learning)*. The target has been relevant journals and conference websites to identify appropriate studies in the limited timeframe of 7 years (2012-2018); the terminus post quem has been 2012 since our intention has been to review modern and technologically facilitated approaches in designing and sustaining CoPs, as well as map characteristics and services comprehensively.

The innovative characteristics of the research presented in this paper evolve around the selection criteria for evaluating the STEM web based and CoPs oriented platforms. Our aim has been to clearly address evaluation criteria that map the CoPs' formation according to Wenger's described model of CoPs [Wenger, 2001] and instead of focusing on evaluating a set of client configurations we have targeted at an empirical approach of evaluating the platforms. The majority of approaches in web based platform evaluation target at criteria technologically based and not designed based [Eaton, 2004], [Ricca, 2005]. Under this context quite popular in literature web based platforms evaluation criteria have been security, performance, support, easiness of use etc., which actually target at system analysis [Fakhreldeen, 2013]. In the case of the present paper, the evaluation criteria have been defined through an instructional design perspective, having Wenger's suggestions for ICT support on the CoP model [Wenger, 2009] as a roadmap. Since supporting "informal STEM" [Allen, 2019] is a major dimension of STEM oriented platforms' learning effectiveness from a pedagogical perspective, it is quite important to define the characteristics of fully developed STEM and CoP oriented platforms for web based learning, evaluate how existing platforms respond to these characteristics and provide heuristics on design guidelines for CoP based and STEM oriented web based platforms. To address these research questions we have used primary grid analysis as an analysis technique for comparative evaluation [Colace, 2003], describing baseline metrics for representing the platforms as alternatives and the factors (tools and services) that have to be taken into account; thus homogenous data presentation has been achieved. Under this context we have selected the systems approach for evaluation which is quite dominant, regarding all respective design features as a system of interactive parts [Saracevic, 2000]. This is actually a user study on which the center of attention is placed on different CoPs' oriented design features in terms of usability and functionality with a view to improve design for future use [Salampasis, 2002].

One of the major aims of this study, has also been to present initial limitations, considerations that came across, but also to emphasize through the presented online STEM platforms their link with state of the art technologies such as IoT as well as the importance of relative theories guiding the development of online STEM platforms. As a consequence core components of the STEM oriented platforms embracing the CoP model emerge out of this process, as presented in Section 4.

3.2 Research Sample

The research sample comprised of fifteen (15) STEM oriented platforms (Table 2 in Appendix). The criteria for including STEM oriented web based platforms in our work has been the ones that on a first reading comply with basic principles of Wenger's theory on building CoPs, such as a) their web based features; b) the inclusion of collaboration tools; c) their free and open access feature; and d) their STEM orientation. In literature, the performance evaluation of web based platforms is mostly the target for comparative studies in the sense of evaluating services provided by platforms cutting across a wide range of systems, interfaces and user communities [Bollen, 2002] [Botturi, 2004]. On the basis of the previous considerations the described evaluation axes in this paper have emerged out of the following four macro fields: system requisites, training resources and community management, user management and services offered to users [Colace, 2003]. Our aim has been to identify web based STEM oriented and CoPs' based platforms which could have the *constructivist feature*, carrying out four different functions such as communication, information sharing, information access, cooperation, engaging learners through active learning, problem solving and project management techniques.

To identify web technologies that the selected STEM oriented platforms depend on, we have combined the use of special advanced web based tools for tracing Content Management Systems such as *Wappalyzer* (*https://www.wappalyzer.com/*), *W3techs* (*https://w3techs.com/*) and *BuiltWith* (https://builtwith.com/) and literature review survey shaping up an integrated strategy, as opposed to a simple browser searching of STEM oriented platform tools. *Alexa* (Alexa.com) as a web evaluation tool, though considered biased towards MS Office and Internet Explorer users, has been used to actually calculate popularity of the selected platforms (Table 2).

The fifteen (15) STEM oriented online platforms, thus, have been included in the comparative study based on the following dimensions' rationale: a) constructivist feature support; b) popularity in the education and market place; c) STEM orientation; d) conducted web research on web based STEM platforms; and e) adoption of contemporary technologies (e.g. IoT). To assess the specified features we have accessed the online STEM platforms through trial user accounts. The comparative evaluation process has been shaped by exploring the STEM oriented platforms' services and tools within the axes of effectiveness (proper use) and the prescribed timescale (2 months) available to evaluate them.

The *actual testing* of the tools and services in the STEM oriented platforms involved the following steps: a) user registration and access on the platforms' tools and services; b) actual use of platforms' tools and services so as to map these with predefined characteristics according to the seven evaluation axes; and c) checking on platforms' effectiveness (e.g. error handling, exploration of prevention mechanisms). There also have been instances (e.g. on testing collaboration tools) for which we used extra accounts, since some utilities could not be tested with the use of one account.

3.3 Data Collection

The evaluation axes as defined and presented in Section 2.4 have been the pillars for conducting the comparative analysis of the STEM oriented platforms. The results of the evaluation process are presented in the following paragraphs.

Platforms support various forms of content management from typical file organization in folders to metadata annotated resource filtering. Content management platforms such as Drupal Commons and Central Desktop may form the baseline upon which the required content management services are built. Besides content management other collaboration services are evolved around content such as managing discussion forums, blogs/microblogs and wikis. Collaborative document authoring is another service providing immediate feedback to the involved participants. Tools, such as Google Documents, allow multiple users to edit documents at the same time with all the edits marked for clear reference. Social bookmarking tools, on the other hand, enable the assembling of useful links to Web content and their cataloguing. Community interaction is enhanced by sharing multimedia content such as photos and videos, in order to capture information and knowledge on a topic. Although it may be possible to include this material within the platform, it is more efficient if one can use external services as the host for the content and import the player's plugins that these on-line sites provide within the platform. The advantage is that the native player can provide an outstanding user experience and the platform administrator does not have to worry about hosting large data files. Examples of such on-line content libraries are YouTube and Flickr. Such content and media sharing tools are central to the operation of CoPs. Finally, data visualization tools are required to analyze and present data mostly in graphical views to assist teaching and learning [Kuosa, 2016].

The majority of the explored platforms are embedding a significant array of content-based features as can be inspected in section A of Table 3 in Appendix. Features in shortage, however, include collaborative authoring and data visualization tools as only four (4) of the platforms are providing either service explicitly.

The aim of Member Interaction services is to bring community members closer to each other and provide a digital space for sustaining their dialogue on topics of interest. In this context social networking should not be confused with the social media, since their purposes are different although the same platforms may be used. The aim here is to create discussions and new ways of interaction between community members. The relationships developed through such interactions are more direct and discussions based on topics of common interest become more personal. Member commenting is also an important issue, because apart from initiating a discussion it can be used as a feedback mechanism. The commenting ability is essential to be supported in the context of most of the tools provided in the platform, whereas equally important is their possible interconnection. Through discussions the social skills of members (e.g. students) can be evolved, questions can be addressed and knowledge on specific topics can be acquired. Webinar services typically facilitate community interaction in terms of distant lectures, seminars and presentations. Community operation is assisted by providing feedback mechanisms to the participants, for example, to rate content types, to provide comments, and to search information based on the access frequency and ratings of other members. Exploiting such mechanisms can facilitate the quick discovery of the most suitable content (e.g. an artifact with explicit features and rating) and the understanding of its development and usage details, especially for large content repositories. The participation of members to community activities is facilitated by survey and poll services. Various question types are provided such as likert-scale, select options, text fields and date as well as results analysis.

Section B of Table 3 in Appendix provides an overview of the member interaction features across the explored platforms. All features have been covered adequately except from webinar services which are found in about half of the platforms (8 cases).

In the Project Coordination module services are provided to create a project, to allocate tasks and to organize activities. Events calendar management is essential to inform community members about planned tasks and for finding data on prior meetings and tasks. New events can be posted to the platform and the calendar array of events can be inspected by every user. By setting access privileges for new events the visibility of the calendar can be restricted only to community members with the proper access rights. The provision of services to evaluate the assessment of task and project milestones is also foreseen. Decision making tools such as ranking ideas, analyzing information through a series of steps and establishing consensus can assist project members to manage various steps in the context of solving practical problems.

The evaluation results for the project coordination axis are presented in Section C of Table 3. Features in this category are underrepresented since only six (6) platforms provide task management and evaluation tools and only one (1) platform is equipped with decision support tools.

The *Incentive and Recognition* axis refers to the practical use of incentives so as to encourage participants to learn through a variety of rewards such as badges, rewards or reputation management systems. Such rewards can be simple markers associated with a username up to a physical prize. Through markers the participants can identify skills or knowledge acquired based on their performed actions. This provides a quick indication of their status and an encouragement for attaining more markers. Physical prizes can be special equipment or hardware/software components that can facilitate project implementations. Another type of incentive is the organization of competitions with prizes for the winners, such as trips to installations that provide educational experiences. A reputation management system can distinguish users who contribute to the community and are considered reliable when they post information or advices. The use of such systems enables the efficient creation of working groups with the appropriate members as well as to identify quality responses provided by the more experienced members.

Section D of Table 3 summarizes the evaluation of the platforms with respect to the incentive and recognition axis. A shortage of mechanisms to reward users is identified as only five (5) platforms provide services for badges and eight (8) reputation management services.

The *Social Media and Communities* category relates to integration of mainstream social media for information dissemination and building both social and personal identity leveraged in the context of community interaction. A goal can be the formation of specific communities within the social media targeted at specific interests and topics and providing a variety of access to users [Manca, 2016]. Typically the presence of a platform in as many social media as possible has benefits, as long as this is an active presence in terms of the frequency of the uploaded posts. Such channels are used to communicate various aspects of the hosting platform, for instance community activities, news, organized events and topics related to education or science. The content that is posted on such sites and is related to educational communities is required to be of equal quality as the corresponding one provided by the platform. Furthermore, the content posted is expected to be an adapted version of the original content found in the platform and the aim is to attract the interest of users in order to revert to the platform for accessing more material. As indicated by the contents of Section E in Table 3, social media and communities are well covered.

The *Supporting Utilities* axis refers mainly to services supporting management aspects such as user authentication, content safety and data input error handling. Notifications assist the operation of active communities and several methods are provided by the platforms such as e-mails, social network notifications and SMSs. Information on platform access and use is provided in the form of metrics reports. Such reports provide figures on various aspects of the platform use such as new members, messages posted, page views, page views per visit, messages posted per week, etc. which can be analyzed in order to optimize platform operation. Section F of Table 3 shows that such basic utilities are present in all platforms.

The *Supplementary Topics* axis refers to augmenting characteristics and services that may not be standard in typical online STEM platforms however their presence can enhance learning practices and promote positive attitudes towards STEM disciplines. Such topics include explicit integration and support of state-of-the-art technologies (e.g. Internet of Things), the adoption of learning theories in the design of online platforms (e.g. active learning, inquiry-based learning, and experiential learning), the provision of learning assistance services, Application Programming Interfaces (APIs) and remote management support.

IoT platforms like Arduino and Raspberry Pi provide many opportunities for supporting STEM educational scenarios. The integration of IoT based tools in this respect is considered as a supplementary platform feature. Pedagogical framing entails the adoption of a learning theory in contrast to a simple repository of resources. As learning assistance services the provision of tools beyond typical educational resources are considered such as simulators, software applications, online laboratories and educational games. APIs are important since they allow for mash up applications which pull data and functionality from platform resources online to combine them in new presentations. Furthermore, a few platforms support the interaction with laboratories that provide access to special equipment. In such cases remote management capabilities are useful, so that the users can manage the equipment from distance. Similar services are of interest in platforms that promote their own hardware boards. Using an account and a suitable working environment allow for remote programming and management of sensors in such boards, without having to deal with intrinsic communication issues. In this context integrated IoT subsystems may offer several services to the users such as controlling an IoT device over the web, collecting data from the devices (e.g. temperature), visualizing the collected data and exporting and downloading the collected data to various formats.

Section G of Table 3 summarizes the evaluation of supplementary features. While learning assistance services are provided by all platforms these are not grounded on a learning theory permeating the platform design. Along the same lines the support of advanced features regarding the integration of state-of-the-art technologies is limited.

One important aspect in valuing these platforms as integrated learning environments is also their educational dimension. In this respect parameters examined include: how learning is organized, which types of educational material are broadly used, which kind of learning theories are used for underpinning the design and development of the platforms (see pedagogical framing in supplementary topics) as well as the levels of interaction among members and how these are shaped by the communication and collaboration tools. The most popular educational material formats are types of evaluation activities, articles, images, pdf guides and handouts. These types support the dissemination and use of Open Educational Resources which are quite popular in distance and online learning.

4 Discussion

The discussion provides an interpretation of the comparative study results and summarizes the responses to the research questions with evidence from the study and generally accepted knowledge. The arguments presented in the following trace the three research questions listed in the Introduction section.

RQ1. Which are the characteristics/properties of an online CoP based platform supporting STEM education?

The added value of STEM oriented platforms supporting the CoP model is related to the following factors: a) they can be used as a hub and digital space for collecting and storing a significant amount of educational material; b) they allow for access in their services by many users; c) they make the search for relevant educational material on STEM less time consuming than searching on the web; d) they allow for the creation of both personal and collaborative spaces; e) they are closer to a model of ubiquitous and mobile learning, f) as integrated learning environments allow students to apply STEM thinking, through collaborative learning and data management .

Assuming an equal weight between features and axes in the proposed evaluation framework (Figure 1) the maximum score that could be attained is thirty six (36). All platforms had a score within at least 50% of the maximum value validating their selection to the targeted comparative analysis. In this context the platform with the highest score, 31, was Go-Lab, followed by The Things Network, with a score of 29, and four other platforms (Arduino, Hackster, Raspberry Pi and UMI-Sci-Ed) with a score of 28. Only 7 of the 15 platforms had a score equal or above 70% of the perfect score, whereas the median and mean score values were 25 and 25.46 respectively. Given these descriptive statistics, it appears that nearly one-third of the features defined are not covered by the platforms indicating a relative features shortage by the existing platforms to support methodically STEM education within the CoP model.

To facilitate the comparison on a mutual percentile scale individual axis scores were normalized by dividing each axis score by the total score. Each axis score is expressed using a 0-1 scale with the maximum value of 1 corresponding to the complete feature coverage and the minimum of 0 to the worst case of no coverage at all. Figure 2 illustrates for each platform a stacked column chart which indicates the impact of each evaluation axis on the total score. The latter is indicated at the top.

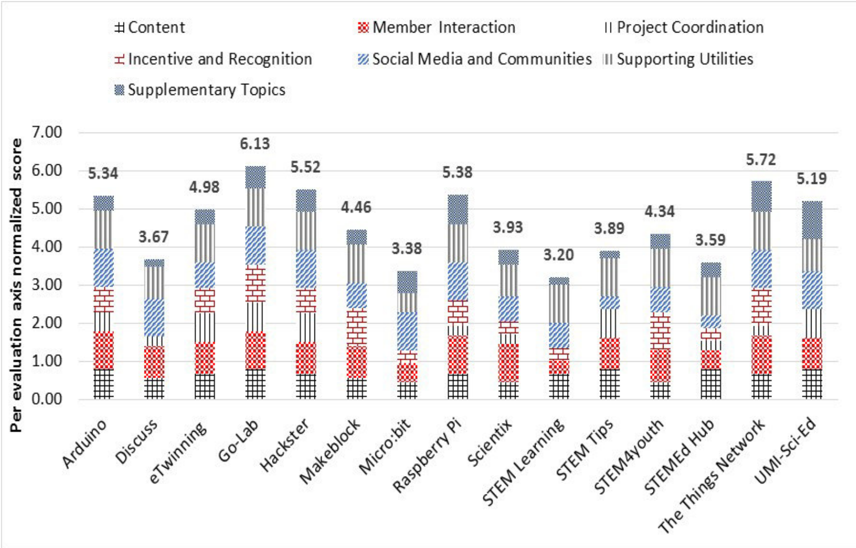

Figure 2: Overview of STEM oriented platforms assessment based on the seven evaluation axes

The normalized total score of each platform is given in Table 4. By inspecting the data provided similar conclusions can be drawn as the ones discussed above.

Arduino	Discuss	eTwinning	Go-Lab	Hackster	Makeblock	Micro:bit	Raspberry Pi	Scientix	STEM Learning	STEM Tips	STEM 4youth	STEMEd Hub	The Things Network	UMI-Sci-Ed
0.8	0.5	0.7	0.9	0.8	0.6	0.5	0.8	0.6	0.5	0.6	0.6	0.5	0.8	0.7

Table 4: Normalized total scores for the explored platforms

RQ2. How current STEM oriented online platforms respond to these properties and compare to each other?

The online STEM oriented platforms evaluated demonstrate commonalities but also points of differentiation regarding their goals, whereas there is a variety in dominant features. For example, Go-Lab is targeted towards the use of visual laboratories, whereas other platforms are more project oriented such as Hackster and UMI-Sci-Ed. Hackster, Scientix, Stem Tips and UMI-Sci-Ed have an orientation in supporting communities of users as a result of their design and platforms' vision. The way communities are formulated and supported in these platforms is critical, since CoPs involve the use of specific domain, community structure and practice interaction supported by appropriate technological infrastructure and a variety of digital tools. There are also platforms, such as eTwinning and Discuss which have set as a goal the formation of communities, however in their case the approach seems to lack features (design characteristics and infrastructure) for developing CoPs in the sense of collaboratively building new knowledge and new projects based on specific tools.

Along the same lines the *scope and aim* of STEM oriented platforms is varied since some of the platforms are targeted mainly in the technological dimension of developing STEM based applications and projects, by using coding and project based educational principles (e.g. Arduino, Raspberry Pi, The Things Network) while others focus on both the technological and pedagogical dimension, in terms of providing guidelines for developing new educational material, or providing templates for building educational scenarios and technology based projects (e.g. STEM Learning, STEM Tips, STEMEd Hub, UMI-Sci-Ed). In the former case *end users* have been people/professionals who have an interest in developing applications based on coding processes, whereas in the latter case platforms target at a broader array of end users such as researchers, practitioners, students, teachers or policy makers.

Regarding the *structure/architecture of the STEM targeted platforms*, there are points of differentiation as some of them encapsulate characteristics of Content Management Systems (such as STEMEd Hub and UMI-Sci-Ed) while others have a more generic structure in terms of mainly providing educational material supported by a communication space, without, however, embedding more elaborated digital tools such as project management, and collaborative document authoring. The majority of the explored STEM oriented platforms provide open access to users, however there are variations in the level of accessing rights since some platforms such as UMI-Sci-Ed, and The Things Network provide some services exclusively to registered users. In some cases, the official involvement of STEM stakeholders is emerging (e.g. in the Scientix platform), however in most of the cases users interact on a personal basis, trying to elaborate on points of their professional interest but not in an affiliated level. Another point for further differentiation is the level of linking the educational material or infrastructure with existing curricula with a clear conclusion being the need for further immersing of curricula topics in the respective STEM oriented platforms.

Figure 3 illustrates the feature coverage per category over all the online STEM platforms explored. Features in the Supporting Utilities, Member Interaction and Social Media and Communities categories are well represented in all platforms with a coverage of at least 80%. On the other hand, the Content category even though is represented in the majority of the STEM oriented platforms, however, with a medium coverage (64.44%) indicating the existence of ample opportunities to incorporate more relevant services and digital tools. As it is also evident from the bar chart, the last three categories, i.e. Incentive and Recognition, Supplementary Topics and Project Coordination require more attention by future online STEM platform developers so as to successfully embrace the CoP model. For example, digital tools on Project Coordination and Management in the level of groups or communities are important so as to establish timelines for procedures to collaboratively building software based products or developing applications. Also more elaborated support and provision of Incentive and Recognition features could help to better orchestrate the users in the learning space and provide a clearer picture of communities' development and lifecycle by providing rich data sets, analyzed through learning analytics.

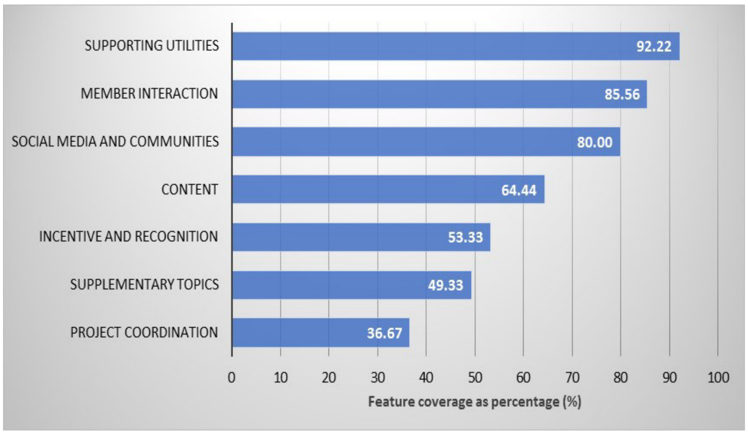

Figure 3: Feature coverage per category over all the online STEM platforms explored

In particular, the use of social media, in a broad scope, is a very important parameter in developing and establishing collaborative learning and as a consequence communities that engage users in collectively building STEM oriented educational material or applications [White, 2009]. In some cases special communities are used, however in most of the cases the same content is used but translated in a variety of languages. For example, Arduino, STEM4youth and Makeblock make use of the same posts in social media such as Twitter and Facebook in English. Twitter and Facebook have been found to be the most popular social media, supporting the explored platforms, whereas LinkedIn is used less.

Regarding the educational material used, more popular formats are guides, video tutorials and FAQ menus, which enable the users to interact with these in their preferred time slot. Reusability of components and hardware is also important in the sense that it relates to the development of community's repertoire and practice.

Major shortcomings, concerning the deployment of the platforms, are identified in tools supporting services such as collaborative authoring, data visualization, decision support and social book marking which are missing in most of the cases. Nevertheless, to develop such platforms towards to integrated educational environments the provision of embedded content management and decision making tools is important. Feature coverage is also found to be limited in certain categories as discussed in the following.

Regarding Project Coordination features, although calendar services are quite popular for tasks such as determining deadlines for authoring an assignment or developing a specific artifact, the management of the tasks is limited to a centralized approach i.e. users are not allowed to make changes in the calendar. Another important parameter is the use of supportive guidelines regarding project management skills related with the actual production of relevant projects and applications. For example, in eTwinning and Discuss communities, users own their calendar, while there are other platforms such as Scientix and Hackster on which an event has to be approved in order to be added in a central calendar. A mechanism for extracting data from the calendar service could be actually important for providing individualized calendar services to users and shaping the timeframe for respective members' and communities' actions. In most of the platforms, task management tools are driven by third party providers, accessed through the web, whereas decision making tools, have not yet been included in the platforms' infrastructure.

Regarding Supplementary Topic features, users' notification could occur also in a mobile device allowing for more configuration choices. The deployment of APIs are also necessary in platforms where users require to develop their own applications. In some cases APIs are used for improving platforms' appearance but users are not allowed to develop their own applications or community based products using data, released publicly in the platform. In order these platforms to shape, integrated learning environments providing affordances for practice based skills, they should involve remote management of material such as the case of building online labs. Though most of the platforms seem to shape learning environments which provide a variety of stimuli to users, suggestions on educational material collected and how it could be further developed and used in authentic educational settings, is missing. Under this scope, a potential improvement would be to integrate pedagogical and selected educational approaches to this material. Another important aspect would be these platforms to allow for adjusting the educational content or its orchestration according to parameters which affect it.

Regarding Incentive and Recognition features, data revealed that in most of the platforms rewards in the form of competition prizes and reputation management systems for assessing user credibility are used. On the other hand, other mechanisms such as the use of badges is limited in only a few cases such as in STEM4youth and Makeblock. Furthermore, the mechanism for earning badges could be better attended and designed. For example, badges should be used to reward users when they accomplish a goal and not for common actions.

RQ3. Which are the design guidelines for a fully CoP based online platform in the STEM domain?

The STEM oriented platforms vary in terms of tools used, pedagogical scope, infrastructure and services provided. However an online STEM platform embracing the CoP model in its ideal form, based on the data already presented, arguably are quite far from expectations. Under this scope, major improvements in these platforms should cater for the following aspects: a) supporting actual tools and services for online constructive interaction such as clear STEM orientation disciplines, state of the art equipment and digital material and specific guidelines for learning / educational interaction and not just downloading educational content under a virtual pedagogical underpinning; b) expanding the target group not just to teachers and professionals but mainly to students; c) creating better motivation for users as well as inspiring the feeling to users of achieving specific goals during their interaction; d) creating and incorporating a variety of digital tools for real time collaborative learning; e) targeting by using social media in a variety of educational topics and not just limiting content to specific (i.e. technological) areas; f) attracting a plethora of users to platform interaction so as to achieve community sustainability; g) maintaining zero cost in using the platform services; and h) always explore new digital tools so as to be integrated in the platform.

A variety in content management and associations channels, as well as providing infrastructure for online project coordination are also important in achieving the ideal version of a platform. The integration of more elaborated feedback and evaluation mechanisms for users and the digital environment as well as the provision of actual infrastructure that supports a variety of user roles are also important. Table 5 summarizes important guidelines for platforms as emerged out of this research, organized according to the [Dube, 2006] taxonomy of online CoPs. The demographics category was not considered since its attributes depend on the characteristics of a specific community and thus a generalization is not feasible.

Design Activity		**Directions**
Organisational #1	Encourage Participation	Visibility: provide subscription reminders, attendance awareness, members directories and visibility
		Participation rhythm: provide calendars, reminders, tip of the day
		Involvement easiness: electronic newsletters, content filtering, ordering mechanisms
Organisational #2	Create Value	Achieve top-down transmission of knowledge: supporting mechanisms obtaining knowledge from experts, specialists, proficient practitioners
		Achieve a culture of participation: allow information in a bottom-up stream for sharing experiences, practices, competences i.e. organize and navigate to any kind of content type supported in the platform and provide advanced search services through content categories, filters, metadata and tags
		Promote life-long learning: applying tutorials, online help, FAQs, virtual tours
Organisation al #3	Crossing boundaries	Integrate other virtual/real environments: publish feeds and news, releasing external events, assigning warnings and alerts i.e. integrate social networking capabilities within the platform in order to foster social interactions and attract new members
		Assist the formation of subspaces on educational aspects: formation of new project groups
Membership #1	Personal Identity	Define profile in terms of personal & professional characteristics
		Provide different levels of participation: provide user management services in order to manage the profiling attributes of participating organizations and participants and assign appropriate access rights
Membership #2	Community Identity	Access not free nor anonymous: control on user participation, sharing multimedia content in order to capture information and knowledge on a topic
		Provide involvement experience and individual history in the community: feedback in the form of rating a content type or providing comments, and finding information according to the ratings and access frequency of members
		Provide tools to assess members value: badge and reputation systems, evaluation of member's contribution

Design Activity		Directions
Technological #1	Participation	Provide several modes of interaction for diverse purposes: sharing knowledge, notification of events, supporting the creation of projects, allocation of tasks and organizing activities with relevant information in order to schedule and realize interaction activities such as discussions, meetings and interviews and the creation of demos/prototypes
		Support reification of soft knowledge: incorporate specific interaction such as discussion groups, document management, synchronous interaction, provide tools for collaborative authoring and data visualization in order to access, use, share data across knowledge levels of community
Technological #2	Verification	Define and implement specific administration, coordination and curation roles: define tasks and actions of stakeholders involved
		Provide tracking and monitoring services: use/generate weekly reports, analytics, data visualization tools
Technological #3	Community development	Support continuous restructuring and customization of both community and supportive software tool: users can create relations between certain content types (e.g. a project may related to a specific forum topic, calendar event, etc.) or integrate social networking capabilities within the platform in order to foster social interactions and attract new members
		Provide evaluation tools for the platform use and the community performance: surveys, polls, etc.

Table 5: Design guidelines for the development of CoP based online platforms in the STEM domain

Several design implications can result in reference to the guidelines assembled in Table 5. From the organisational point of view, the platform design is vital to enable the connection of community members, even with other people sharing analogous interests, independent of their distance. This proposition encourages designers to pay attention on how the platform supports such connections and more importantly how it could be extended to meet this necessity. Along the same lines, supporting in real-time the reaching and conversing to other people, members or not of a CoP, caters for processes that are creating common experiences, which is essential for maintaining the CoP identity alive. This proposition encourages designers to pay attention, for example, to feedback channel tools, such as micro-blogging and chat. From the membership point of view, a fundamental design goal is the fostering of legitimate peripheral participation in CoPs [Lave, 2002]. In this context, novice CoP members are given the opportunity to be involved, via translucent methods or practices, in order to be able to incorporate their contributions in the workings of the community. For this objective, the platform design should support beginners on a gradual way (e.g. by assigning tasks of gradual difficulty and independently), thereby, starting with a participation in the periphery of the activities of a CoP and proceeding progressively by assuming more demanding tasks. Furthermore, paying attention to peoples' motivations can promote their participation towards using a platform more frequently and thus contributing to the goals of a particular CoP. People take actions not just for private profit but for other psycho-social reasons too, such as wellness and pleasure, social inclusion and connectivity, reputation and appreciation. The fulfilment arising from being involved and contributing to a community to solve common problems can be interpreted as incentive, which can be affirmatively fostered and intensified when the community organization and resolution, as reflected in the platforms tools, acknowledge and reward such contributions. Finally, from the technological point of view, it would be beneficial to the users if the platform could support combinations with systems and tools that users are familiar with. The design concept of mashups based on blending different APIs and data sources to produce innovative tools is advocated as a potential path to cover this option. System usability issues should be also taken into account in the platform design so that users could start using the platform swiftly, and be able to contribute to a CoP with a limited effort. Software engineering methodologies based on user-centered and participatory design [Sanders, 2002], enable the active participation of end-users at the design process with benefits measured on the improved acceptability of the developed platforms.

Regarding the educational content used for STEM education in K12, important features are the interdisciplinary potential of its use, and providing examples of good practices and role models in research and science, as also indicated in STEM 2026 vision report [STEM, 2016]. Successful STEM oriented activities are broadly disseminated, easily accessed and they invite intentional play and risk. STEM involves constructivist based activities, searching for uncertainty, recognising ambiguity and learning from failure [Camins, 2012]. Intentional play activities can support this type of learning experience by providing students with time to explore their uncertainties, construct knowledge from experience, and strengthen relationships [Bertrus, 2015], [Nell, 2013] intriguing also creativity as students learn through a combination of observation and play-based practice that incorporates opportunities for trial-and-error. While a non STEM CoP could be based on collaborative activities that actually focus on knowledge creation and sharing, a STEM based CoP should make use of activities that have the features described earlier emphasising on skills. CoPs' activities are formed by a set of actions that are often organized in chain and intend to achieve the objective of this activity [Daele, 2009]. These activities consist of goal-directed actions that are conscious and its constituents are not fixed but they can dynamically change, mediated by artifacts (tools, documents, etc.) with an objective to reach outcomes. STEM literacy captures the sense of purposeful integration of the disciplines, while not having to equally include all four (Science, Technology, Engineering, Mathematics) in every lesson. In a science lesson, the main perspective would be scientific literacy, incorporating mathematics and the other disciplines as appropriate [Breiner, 2012], [Judson, 2013]. Designing also effective and innovative STEM activities implies orientation towards career activities and career interests. For example, activities that are unusual and creative, promoting responsibility and leadership, analysis and investigation but also activities important for helping others and being concerned for welfare [Dubney, 2012], [Zhang, 2012].

5 Conclusion

Online CoPs for STEM learning embrace a variety of stakeholders and environments that altogether define a wealth of learning opportunities for youngsters. Properly designed online CoPs can enable students to be engaged, well-informed and skillful in the STEM fields as they progress in their education. Since the implementation of online CoPs is not a trivial task in this study we argue on the necessity of a design framework which motivates the application of the CoP model to the STEM education through properly designed online platforms. In this context, the common features required to build CoP enabled online platforms to support STEM education were identified and classified in categories to form an evaluation framework for this domain. A comparative analysis of several STEM oriented web based platforms was conducted, revealing a shortage of features to support methodically STEM education within the CoP model. As a result of the analysis a generic framework of design guidelines was formed for building STEM oriented online platforms that embrace the CoP model. Part of the design guidelines have been already integrated in one of the platforms (UMI-Sci-Ed platform) explored and as a future work its elaboration following the complete set of design directions, is foreseen. Such an elaboration of technological platforms would permit the assessment of the proposed design guidelines that can lead to further improvements or refutations.

Acknowledgements

Part of this work has been supported under the framework of HORIZON 2020: UMI-Sci-Ed project No 710583. The authors wish to thank the domain experts who provided feedback on the use of CoP evaluation axes as presented in this paper.

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Appendix

Platform	Basic Goal & Characteristics	Launch Year	Ranking[a]	Ref. / URL
Arduino	Arduino Project Hub aims to promote education with the use of the Arduino board in different educational projects. *Powered by Hackster; Low cost board and components; Web editor for programming; Worldwide communities.*	2006	2.238	[Sohn, 2014] www.arduino.cc
Discuss	To provide a rich variety of tools for asynchronous and synchronous communication for communities of practice on lifelong learning. *Communities' social services; Tools development; Knowledge sharing; Events.*	2015	12.025.678	[Doyle, 2015] www.discuss-community.eu
eTwinning	To encourage collaborations among EU schools through the use of ICTs. *Collaborations between schools' staff; Projects development; Communities with specific goals; Social profiles.*	2005	25.986	[Papadakis, 2016] www.etwinning.net
Go-Lab	To help teachers enrich their teaching practices with web tools and pedagogical approaches. *Virtual laboratories; Web-applications for teachers and students.*	2013	602.958	[de Jong, 2014] www.golabz.eu
Hackster	To support users in designing and programming electronics in various topics. *Dedicated communities on STEM sciences or specific hardware; Projects and their guides; Reusability of hardware in projects.*	2014	12.692	www.hackster.io
Makeblock	To take education to the next level by developing STEM hardware, software and educational resources. *Educational robots; Resources; STEM kits; Programming tools.*	2013	53.181	[Merino, 2016] www.makeblock.com
Micro:bit	To improve learning and teaching in a variety of science subjects through the use of a tiny microcomputer. *Low cost programmable board; Lessons; Teaching Resources.*	2016	29.983	[Gibson, 2017] www.microbit.org
Raspberry Pi	To disseminate the use of a low-cost microcomputer for educational purposes amongst others. *Low cost device and many projects; Resources for educators; Community websites; Raspberry Jams – meeting events.*	2012	3.210	[David, 2018] www.raspberrypi.org
Scientix	To support collaboration between STEM teachers, researchers or other professionals from European countries.	2010	712.365	[Melcu, 2017] www.scientix.eu

Platform	Basic Goal & Characteristics	Launch Year	Ranking[a]	Ref. / URL
	Matching tool to find partners interested in a project; Resources repository; Organizing events; CoP support.			
STEM Learning	To promote STEM subjects to young people and help them progress towards STEM-related careers. *Educational resources; Continuing professional development; Teacher coaching.*	2016	84.674	[Holman, 2017] www.stem.org.uk
STEM Tips	To support STEM teachers' preparation by providing mentoring instructions, discussions, resources and tools. *CoP support; Public or private questions and answers; Collections of resources and tools; Personalized solutions to problems.*	2013	4.166[b]	[Jones, 2016] stemtips.education.ufl.edu
STEM4 youth	To promote the value of STEM methodology and products for youngsters exploring STEM future career. *Multidisciplinary educational materials; Educational scenarios.*	2017	15.470.594	[Brzozowy, 2017] www.stem4youth.eu
STEMEd Hub	To improve learning in STEM disciplines with the support of CoPs. *Many communities that create resources; Online presentations; Lesson plans; Seminars.*	2011	920.623	[Lehman, 2015] www.stemedhub.org
The Things Network	To help users learn and develop IoT applications through a set of open tools and an open network. *Communities on IoT topics; Labs/Use cases/Guides; Crowd-funded IoT network.*	2015	106.099	[Blenn, 2017] www.thethingsnetwork.org
UMI-Sci-Ed	To exploit Internet of Things and Ubiquitous and Mobile computing to enhance the attractiveness of science education for young people. *Educational scenarios; Communities; IoT projects; Open repository.*	2016	18.946.793	[Goumopoulos, 2018] www.umi-sci-ed.eu

[a] Ranking is a popularity measure and is based on the Alexa ranking system (Alexa.com). Smaller ranking number can show higher popularity in users. The popularity report has been created on July 2019 based on a 3 month period.

[b] The ranking value reported actually measures the popularity of the University of Florida website and not the actual STEM platform

Table 2: Selected platforms' profiles

	Arduino	Discuss	eTwinning	Go-Lab	Hackster	Makeblock	Micro:bit	Raspberry Pi	Scientix	STEM Learning	STEM Tips	STEM4 youth	STEMEd Hub	The Things Network	UMI-Sci-Ed	**Feature score**
Content management & file repository	✓	✓		✓	✓			✓		✓	✓	✓	✓	✓	✓	11
Blog	✓	✓	✓		✓	✓		✓	✓	✓			✓	✓	✓	11
Microblog	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	14
Forum	✓		✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	11
Wikis	✓			✓		✓	✓						✓	✓	✓	7
Collaborative authoring			✓		✓						✓		✓			4
Social bookmarking	✓	✓		✓	✓	✓		✓		✓	✓	✓	✓			10
Multimedia content & libraries	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	15
Data visualization			✓	✓							✓				✓	4
A. Content axis score	7	5	6	7	6	5	4	6	4	6	7	4	7	6	7	
User profile and social networking	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	15
Member commenting	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	14
Discussion tools	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	14
Webinar services	✓	✓	✓	✓				✓	✓	✓	✓			✓		9
Content rating & popularity	✓	✓		✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	12
Polls & Surveys	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	13
B. Member Interaction axis score	6	5	5	6	5	5	3	6	6	2	5	5	3	6	5	
Event calendar		✓	✓	✓	✓			✓	✓				✓	✓	✓	9
Task management	✓		✓	✓	✓						✓				✓	6
Task evaluation	✓		✓	✓	✓						✓				✓	6
Decision support											✓					1
C. Project Coordination axis score	2	1	3	3	3	0	0	1	1	0	3	0	1	1	3	
Badges				✓		✓		✓				✓		✓		5

	Arduino	Discuss	eTwinning	Go-Lab	Hackster	Makeblock	Micro:bit	Raspberry Pi	Scientix	STEM Learning	STEM Tips	STEM4 youth	STEMEd Hub	The Things Network	UMI-Sci-Ed	**Feature score**
Rewards systems	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓		11
Reputation management systems	✓		✓	✓	✓	✓						✓	✓	✓		8
D. Incentive and Recognition axis score	2	0	2	3	2	3	1	2	1	1	0	3	1	3	0	
Social media sites	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	13
Specific communities	✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓	✓	12
Adapted content	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	12
E. Social Media & Communities axis score	3	3	2	3	3	2	3	3	2	2	1	2	1	3	3	
Authentication	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	14
Content access permission	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	14
Data error handling	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	14
Notifications	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	14
Metrics	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	14
Online help	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		13
F. Supporting Utilities axis score	6	5	6	6	6	6	3	6	5	6	6	6	6	6	5	
Pedagogical framing			✓	✓				✓	✓			✓			✓	6
Learning assistance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	15
IoT integration	✓				✓		✓	✓						✓	✓	6
APIs					✓	✓	✓							✓	✓	5
Remote management				✓				✓					✓	✓	✓	5
G. Supplementary Topics axis score	2	1	2	3	3	2	3	4	2	1	1	2	2	4	5	

Table 3: Evaluation results per axis